

SPECIAL ISSUE! THE INVENTION AWARDS

THE TEN
GREATEST
INVENTIONS
OF THE YEAR

BRE PETTIS, co-founder
of MakerBot Industries,
3-D printed everything on this
cover (including himself).



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05
CONTENTS
15

PAGE 34

NINTH ANNUAL INVENTION AWARDS

With the help of ace inventor Bre Pettis, we celebrate 10 ingenious creations that started out as scrappy ideas. Plus, Pettis shares his advice for making products that truly break ground.

Featuring

The Rise of the Incredible, Edible Insect

They're high in protein, minerals, and good fats and far more sustainable than beef. Welcome to the new food movement.

BROOKE BOREL
PAGE 44

Nothing but the Truth

You can't take emotion out of science—nor should you.

ALAN LIGHTMAN
PAGE 50

The Hacker's Guide to Smart Homes

Popular Science's five-step plan for turning your home into a data-gathering intelligent environment—with or without Siri.

CORINNE IOZZIO
PAGE 52

The Church of Church

George Church already revolutionized biology once. Now, he wants to store data in DNA, bring back extinct species, wipe out malaria, and map the brain.

JENEEN INTERLANDI
PAGE 56

Departments

Feed

06 From the Editor
08 Peer Review

Now

11 The Sony Walkman returns—better than ever
12 Ten things we love this month
14 A 1,250hp hybrid racecar
16 Your favorite technologies came from a World's Fair
18 How Pebble plans to win the smartwatch wars
22 Action cameras for everyone

Next

25 Nature's strongest material, dethroned
26 A geologist determined to blueprint Earth
28 Maglev elevators that will reshape skylines
30 Are India Pale Ales an endangered species?
32 Phone home: Time to message aliens

Manual

65 Use soft robotics to build a spare hand
68 Bionic boots for a 25mph stroll
70 Hackett turns a junked TV into a crystal radio

72 Hack your car's infotainment system
74 Meet the engineer behind thrilling rides

End Matter

79 Ask Us Anything: Do babies use the same facial expressions as adults?
86 From the Archives



Bre Pettis's trove includes characters from his 3-D-printed movie, *Margo*.



ON THE COVER
Photograph by Kareem Black

Elements of Invention

As editor in chief of *Popular Science*, I get asked a lot of questions. Some of them are reasonable: Why is the sky blue? (Air molecules scatter blue light more effectively than red.) Some of them are not: Why can't I communicate with my cat? (Try listening.) But the most persistent question is, What does

it take to become a great inventor?

My typical response: If I had that kind of lightning in a bottle, I'd be drinking it myself. Besides good timing and even better luck, it's hard to pinpoint what makes certain inventors successful. They tend to be creative, exceptionally persistent, and tolerant of risk. But beyond that, they are just people, and people come in all stripes. Tesla and da Vinci were ingenious. Steve Jobs was fastidious and business-minded. Thomas Edison was ruthlessly

pragmatic; he was said to have set quotas for himself—a small breakthrough every 10 days and a big one every six months.

The only thing that stands out about successful inventors is that they are exceptionally rare. And one of them is on our cover this month.

In 2007, Bre Pettis, an artist and former schoolteacher, co-founded the hackerspace NYC Resistor. Its members wanted a 3-D printer, but the technology, which had been around since the 1980s, was

expensive and its application, almost exclusively industrial. A few hackers started working with open-source designs. Pettis partnered with two of them, and they debuted their first consumer product, the CupCake CNC, in 2009. The invention became a business, MakerBot Industries, which Pettis sold four years later for around \$400 million. He's now on to his next project, Bold Machines, a 3-D-printing workshop that helps artists and entrepreneurs transition quickly from rough ideas to working prototypes. "We basically accelerate the future," Pettis says.

Every May, *Popular Science* publishes the Invention Awards, in which we celebrate the year's best independent inventions—those scrappy creations born of a garage or workshop, not an industrial lab. Who better to help us assemble that list than Bre Pettis? Together, we dug up some extraordinary awardees, as you'll see beginning on page 34, and

THE ONLY THING THAT STANDS OUT ABOUT SUCCESSFUL INVENTORS IS THAT THEY ARE EXCEPTIONALLY RARE. AND ONE OF THEM IS ON OUR COVER.



Pettis shared his tips for aspiring inventors. He also graciously helped us 3-D print the *Popular Science* logo on the cover and uploaded the design files to Thingiverse.com so that you can print it too.

No story about invention, however, would be complete without a caveat. Not all those featured will make it. Developing a successful prototype and developing a successful company are not necessarily the same skill. But all the ideas have tremendous potential, as do the inventors behind them. You never know. You just may see one of them on our cover one day.

Enjoy the magazine.

Cliff Ransom
Editor in Chief

Contributors



Alan Lightman

As a scientist, Alan Lightman has made fundamental contributions to the field of astrophysics. As a writer, he has published dozens of celebrated novels and essays. "Science and arts reflect the full range of the human mind," Lightman says. "We are both rational and intuitive, deliberate and spontaneous." He reflects on the human nature of scientific research in "Nothing but the Truth" (page 50).



Andrew Terranova

"I enjoy working on projects that entertain me and my kids," says engineer and tinkerer Andrew Terranova. He's built a toy airplane from a hot water heater, a steampunk bank that eats money, and several exhibits for a children's museum. Robots are a special favorite. This month, he dabbles in soft robotics for "Wave Hello to a Soft Robot Hand" (page 65) in Manual.



Kareem Black

The innovation workshop Bold Machines is filled with 3-D-printed gadgets, '80s boomboxes, even a DeLorean. The space and its contents, lovingly curated by Bre Pettis, inspired the playful aesthetic of this month's cover image. "It was like being inside a comic book," says photographer Kareem Black. "There was a 15-year-old boy inside me going insane. It was the biggest toy factory ever."



Jeneen Interlandi

When writer Jeneen Interlandi met George Church in his Harvard lab, she was in familiar territory. A decade prior, she worked in a genetics lab just across the street. "He is in a whole other stratosphere of genius but remains very personable," says Interlandi, who profiled the renowned scientist for "The Church of Church" (page 56). "Talking with him reminded me of how much I love molecular biology."

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Peer Review

SELLING POINTS

In "Cultured Couture" [March 2015], writer Daniel Grushkin took readers inside designer Suzanne Lee's biotech lab, where she grows leather from cells.

I worked in cotton production back in the "bad old days" of weekly insecticide applications. So Grushkin's statement that "cotton farming typically uses intensive pesticides" stood out to me as stunningly out-of-date in an otherwise fascinating piece. American cotton farmers still use insecticides but nothing like in the early 1990s. Now, they spend money on the latest insect-resistant GMO seed.

Ben Barstow, Palouse, Wash.



less insecticide, it has led to the increased application of the herbicide glyphosate.

I was particularly intrigued by the possibility of clothes that adapt to climate while reading about Suzanne Lee growing clothing. You could have the same jacket serving as a windbreaker in the spring and a parka in the winter. You could also have a shirt that brightens in the sun and darkens at night, thus regulating heat.

Douglas R. Benn, Spokane, Wash.

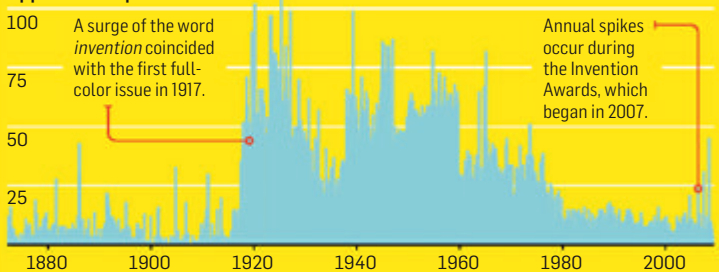
We Apologize ...

Hitting the deadline for "The Science of Stress" [March 2015] proved a little, well, stressful. That may be why we mixed up the labels for the stress monitors on page 47. They're correctly pictured on popsci.com/stresstest.

A HISTORY OF INVENTION

Popular Science has been covering innovation since the magazine's inception in 1872. (This year's Invention Awards start on page 34.) Here's how often the word *invention* has appeared in our pages, either in articles or advertisements.

Appearances per issue



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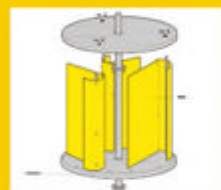
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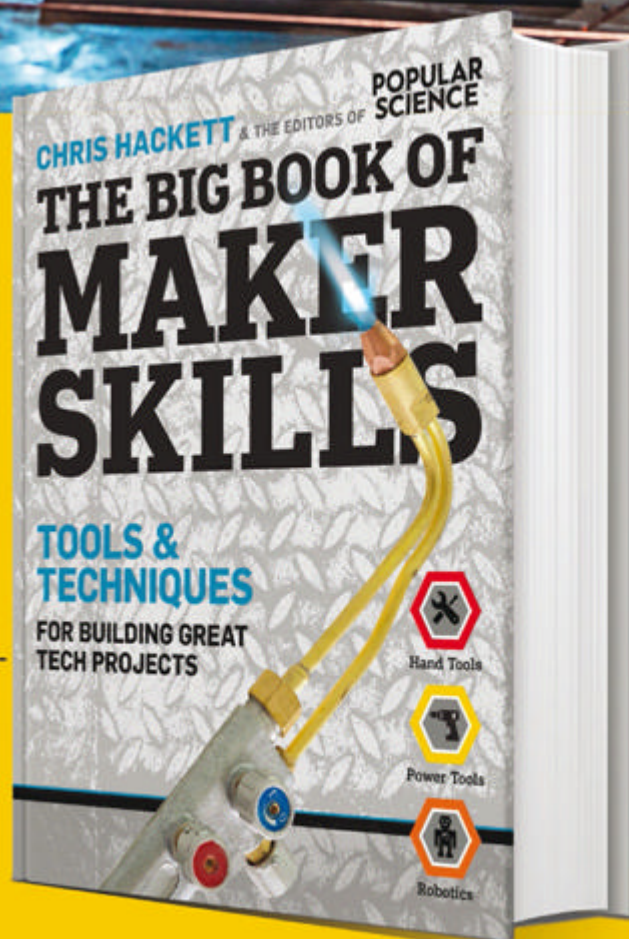


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EDITED BY **Michael Nuñez & Lindsey Kratochwill**

RETURN OF THE SONY WALKMAN



Portable music players are everywhere you turn: smartphones, tablets, iPods, and laptops. But to the true audiophile, it's all junk. That's because most play compressed sound files—great for jam-packing your hard drive with music, bad for sound quality. The new Sony Walkman ZX2 aims to fix that.

This portable hi-fi music player is a far cry from the original Walkman that launched a million mixtapes when it debuted in 1979. The ZX2 plays just about every file type on the planet, and when it's paired with a headphone amplifier, there aren't many products that can match it for quality and tone—even Neil Young's Pono Player.

If you've already committed your iTunes money to a monster digital collection, don't start hitting the delete key. Sony's DSEE HX technology upgrades those compressed files so that they sound like studio-quality high resolution. That means you can crank up the volume as loud as you want and never worry about distortion.

MICHAEL NUÑEZ



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LINDSEY KRATOCHWILL

1 THE INGENIOUS MR. PYKE

Writer Henry Hemming brings to life the genius of Geoffrey Pyke, an inventor and war reporter (among other things), who once convinced Winston Churchill to build an aircraft carrier out of ice. That's just one odd turn in the adventurous tale. **\$27**

2 OSPREY ATMOS AG

Osprey's new pack shoulders some of a backpacker's burden with its new 3-D suspension: a layer of seamless mesh, a hip belt, a tensioned peripheral frame, and a load-balancing harness. The fit will tempt you to pack a few extra luxuries. **From \$230**

3 WIHA BI-CUT SUPER CUT

The power button on Wiha's wire and chain cutter doubles the tool's leverage by changing its pivot point. It's great for when you need to make an extra tough cut. **From \$40**

4 SUNZAPP

Developed by communications firm Klein Buendel in partnership with NOAA and the University of New Mexico, the sunZapp smartphone app uses UV light forecasts to tell you when to apply sunscreen. The catch: Advice only works if you follow it. **Free**

5 GROW

This collector's edition game imitates life. Players build a 3-D

board into a tree and in the process guide its growth. To win, players fend off beetle attacks and cultivate the healthiest flowers of their color. **\$125**

6 INTEL COMPUTE STICK

A TV can become a full-fledged PC with Intel's Compute Stick. The dongle-size device comes loaded with Windows, 2 GB of RAM, 32 GB of storage, and even a USB port. Go on, build your PowerPoint on the big screen. **\$150**

7 HUSH

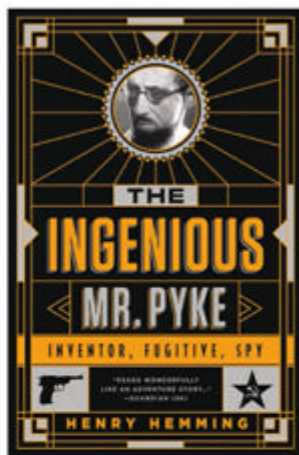
Earplugs are great for blocking out a snoring roommate or a night-owl neighbor. But they muffle important noises too. Hush earplugs use Bluetooth to send alerts when your alarm goes off or an emergency call comes through. **\$150**

8 YETI RAMBLER COLSTER

Hot summers call for cold beverages and that requires something more than a plain old foam cozy. Yeti gave the Colster double-wall insulation to vacuum-seal cool air in and a gasket to hold your cold one in place. **\$30**

9 QARDIOBASE

Weighing yourself is not often a pleasant affair. Qardio lightens the mood with its new smart scale. Among other capabilities, it presents your results in emoticons and with haptic feedback, instead of harsh, unfeeling numbers. **\$149**



1



2



4



6



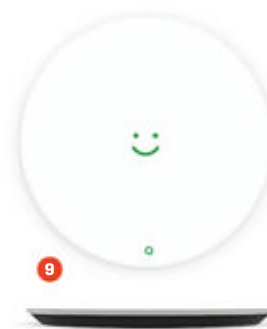
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7



5



9

10 TOMORROWLAND

Inspired by Walt Disney's vision of futurism, this time-travel adventure follows a science-obsessed teen who stumbles into a world of technological possibility. She's met there by a former boy genius, played by George Clooney, naturally. **May 22**



CLOCKWISE FROM TOP LEFT: COURTESY PERSEUS BOOKS; COURTESY OSPREY; COURTESY CRICKET GAMES; COURTESY QARDIO; COURTESY WALT DISNEY PICTURES; COURTESY HUSH; COURTESY INTEL; COURTESY KLEIN BUENDEL; COURTESY WIHA



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A 1,250 Horsepower Monster

↓
When it comes to maneuvering a 200-mile-per-hour racecar, auto engineers tend to hew to a long-held belief: Rear-wheel drive is better than front-wheel drive for handling and weight distribution. Nissan's

new GT-R LM Nismo may turn that notion on its head. It's the only front-wheel-drive racer in the elite LM P1 prototype class at the 24 Hours of Le Mans World Endurance Championship, which starts June 13, in Le Mans, France.

Nissan engineers placed the

The GT-R LM Nismo's generates about 500 horsepower with its combustion engine. The ERS adds 600–700 more.

GT-R's twin-turbo V6 engine up front to shift the weight there. It's a counterintuitive approach: Engineers typically distribute weight evenly for balanced handling. But behind the GT-R's engine sits a kinetic energy recovery system (ERS), which captures energy during braking and stores it for later use. Most teams in the LM P1 class employ ERS for added horsepower and acceleration, but Nissan's team found a clever way to exploit it.

Moving the engine forward makes the front brakes work harder. That creates more kinetic energy to harvest and could boost the car's chances of winning. But the biggest payoff could come offtrack, when Nissan applies the same technology to increase acceleration and fuel economy in its production vehicles.

MATTHEW DE PAULA



CAR NEWS YOU SHOULD CARE ABOUT



1

At the CyberAuto Challenge in February, a 14-year-old hacked a car using \$15 worth of Radio Shack computer parts. The stunt, put on by auto parts maker Delphi, shows how vulnerable cars with cloud-based navigation and infotainment systems have become.

2

The United Kingdom will see the first driverless cars on public streets this year, when Oxford University begins testing a modified Nissan Leaf. The move puts the U.K. ahead of the U.S., where public testing is bogged down in bureaucratic red tape.

3

The Intelligent Damage Detection System being developed by German parts supplier Hella uses small piezoelectric sensors placed behind auto body panels. The sensors generate an electric charge under pressure, indicating when the vehicle's shell takes damage.

4

Auto parts supplier Continental is building an augmented reality app to guide mechanics through problems. The tablet app connects wirelessly to a car and walks a user through diagnosis and repair. Continental expects the tool to be available in late 2016.

DESIGN OF THE MONTH



Bentley EXP 10 Speed 6

This two-seat concept car heralds big change for Bentley, especially after two years of incremental improvements. It's a reinterpretation of Bentley's traditional styling—for example, the grille is set lower and squared off—and modernizes the cockpit with a high-resolution touchscreen. It also uses new manufacturing techniques, such as 3-D metal printing, for the front grille mesh, tailpipes, and door handles.

280

Number of miles (roughly) that the 2017 Audi R8 e-Tron electric sports car can run on fully charged batteries, more than double the range of the previous R8 e-Tron



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YOU OWE YOUR DAILY ROUTINE TO THE WORLD'S FAIR



Began in 1851, the World's Fair once served as an open showroom for technical oddities, scientific breakthroughs, and cultural mash-ups. Although it still draws millions of visitors every five years, upstarts like the Consumer Electronics Show and Apple's special media events have long since eclipsed its role in breaking tech news. Today, the fair focuses on global challenges: This year's Expo 2015, which starts May 1, in Milan, Italy, will explore world hunger. Yet, it's the World's Fairs past that define our lives now; they exposed people to technologies that at the time seemed bizarre and futuristic—but today seem quite familiar. **AMANDA GREEN**

8 A.M.

Tuck into a carb-heavy breakfast of **Shredded Wheat**, created by inventor Henry Perky, or, if there's a chill in the air, **Cream of Wheat**, invented by miller Tom Amidon. These cereal-aisle staples both debuted at the World's Columbian Exposition in 1893 in Chicago.

9 A.M.

Tune in to *The Today Show*, courtesy of RCA. The defunct company pioneered the **first television broadcast** at the 1939 New York World's Fair, streaming live footage of Franklin Delano Roosevelt on its early TVs, called TRK-12s (for their 12-inch tube screens).

11 A.M.

Plug in your laptop at the local Starbucks and think of inventor Harvey Hubbell. He debuted the **detachable plug** at the 1904 Louisiana Purchase Exposition in St. Louis. Before that, you hard-wired devices to live post terminals—time-consuming and dangerous.

2 P.M.

Skype with mom. If she complains about your new-fangled technology, remind her that Bell Labs demoed the **Picturephone** at the 1964 New York World's Fair. Huge lines formed to use its tiny screen and push-button phone to see and talk to visitors at Disneyland in California.

4 P.M.

Kill some time playing Candy Crush Saga on your smartphone, courtesy of Former Oak Ridge National Laboratory scientist Sam Hurst. He wowed the 1982 World's Fair in Knoxville, Tennessee, with a curved-glass **touchscreen technology** he later called Accutouch.

7 P.M.

Find a date on OkCupid. **Computer hook-ups** go back to the 1964 New York World's Fair. Parker Pens connected 1.2 million fairgoers to pen pals around the globe with a computer that matched ages and interests. It had hoped to spur lifelong friendships (and pen buying).

10 P.M.

Head to an **IMAX theater** with your date to see *Tomorrowland*. The format first captivated moviegoers at Expo '70 in Osaka, Japan, with the 17-minute IMAX-ready *Tiger Child*. Don't forget the **popcorn**, first popularized at the 1901 Pan-American Exposition in Buffalo, New York.

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HOW PEBBLE'S CEO PLANS TO WIN THE SMARTWATCH WARS

EDITED AND CONDENSED BY LINDSEY KRATOCHWILL

Long before Apple dove into the smartwatch business this spring, a little company called Pebble made a big splash—and set a \$10-million Kickstarter record—by debuting an intelligent time-piece that provides emails, texts, and music controls. Pebble Time, its newest iteration, ships this month and builds on the original with a color e-paper display and a built-in mic. But after Apple's gorilla-size entry into the market, can Pebble stand its ground? Eric Migicovsky, the company's founder and CEO, gives us his view—and advice for his new competitors.

49

Number of
hours it took
Pebble Time
to raise its first
\$1 million on
Kickstarter



Popular Science: First things first. Why did you make crowdfunding and open source part of your strategy?

Eric Migicovsky: We were a small company—only five people. When we launched, on Kickstarter, people all over the world pumped our tiny project up to a scale we had never imagined. But more important, they spotted a product area that was completely new. No one was talking about smartwatches in 2012, except for these people. Our users gave us immense feedback, helped show what was working, what wasn't. That guided us and directly influenced what Pebble Time is.

PS: You must have some worries about competition from Apple.

EM: We focus on something no one else in the world focuses on. If you

continued on page 20 →

How can you make batteries love dancing?

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The Platform / continued from page 18



A low-wattage e-paper display gives Pebble Time a weeklong battery life.

look at the original Apple announcement, it shows a screen with a clock in the center and apps surrounding it. That struck me as another home screen I have to manage. We've learned that apps are not the correct paradigm or correct interaction model to use on your wrist.

PS: So do you have advice for them?

EM: Oh, definitely. We learned people like using a watch as a watch. They want something durable that they don't have to treat carefully like a smartphone. The future of smartwatches is not siloed apps on your wrist. The future of smartwatches is a blended timeline that lets you see what's coming up next at a glance. That's what Pebble's Timeline software does.

PS: What are some of the trade-offs for smartwatch wearers?

EM: It doesn't replace your phone, first off. You can't make calls from our watch. Though, when you think about it, that's not what a watch should do. You have a phone for that. What a watch does is tell time, and that's the way it's been for the last 100 years. We've added this extra layer of context alongside time. Because 8 a.m. means something different for different people. And Pebble Time helps you get information that's personal to you, that's important to you, throughout your day.

PS: What do you think the future holds for smartwatches?

EM: We're in the early days of smart-

**“I THINK OUR
ATTITUDE
IS A LITTLE
DIFFERENT. THIS
IS LITERALLY ALL
WE DO. WE MAKE
PEBBLE.”**

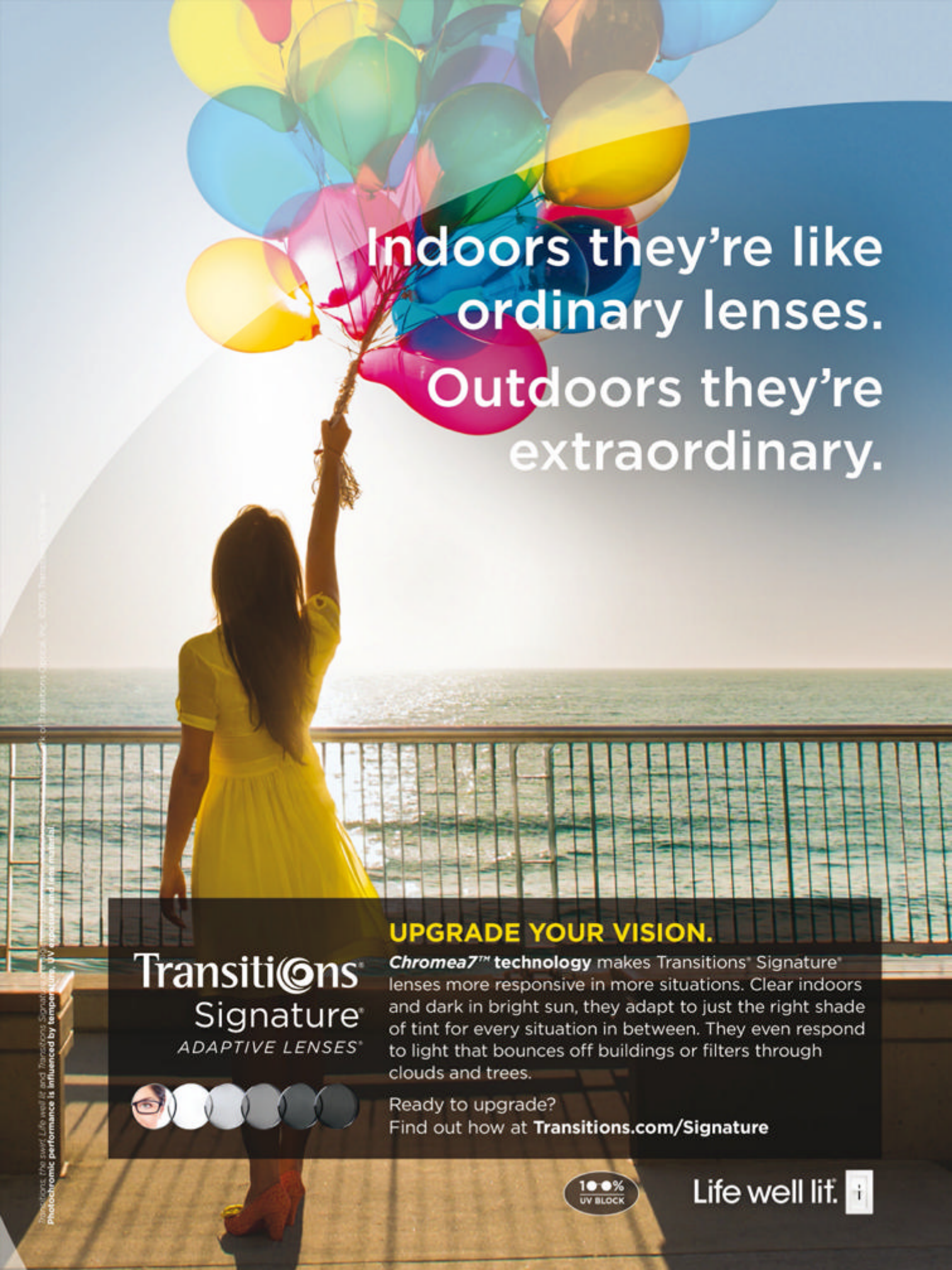
watches. But I'm excited about the future. If you looked at smartphones in 2007, would you have predicted things like Uber? Spotify? Instagram? We're at the same point with Pebble, where we're doing these crazy things that people love, but there's so much opportunity.

PS: How has wearing a smartwatch affected your life?

EM: I've been wearing a smartwatch for five years; it's become incredibly intertwined with how I work. I rarely take out my phone to check emails. If something important comes through, I see it. But more than anything, it allows me to relax and know that I have something else that's helping me get stuff done.

PS: Which watch did you wear before you invented Pebble?

EM: The funny thing is, I didn't actually wear a watch before starting a smart-watch company. 📱



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1

POLAROID CUBE

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Max photo resolution 6 megapixels
Max storage 32GB MicroSD
Battery life 90 minutes
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2

SONY 4K ACTION CAMERA X1000V

Price \$500
Max video resolution 1920x1080 at 60fps
Max photo resolution 8.8 megapixels
Storage capacity 16GB Memory Stick Micro (Mark 2)
Battery life 60 minutes
Best for Lifelogging moms and dads who don't mind fewer mounts but still want great video

3

GOPRO HERO4 BLACK

Price \$500
Max video resolution 3840x2160 at 30fps
Max photo resolution 12 megapixels
Max storage 64GB MicroSD
Battery life 60 minutes
Best for Adrenaline fiends who need the most durable—and most expansive—mount collection



TINY, RUGGED CAMERAS FOR EVERY PURPOSE

First intended for BASE jumpers, mountain bikers, and skateboarders seeking YouTube glory in crisp HD video, action cameras have grown way beyond their original purpose. Compact and lightweight, they have become an unexpected favorite among daily commuters, casual hikers, and even parents feeding their kids, all looking to capture modest—but, to them, memorable—moments.

As the usage range has broadened, so have the cameras' functions.

Sony recently upped its game with a 4K cam. Polaroid put new durable mounts on its most inexpensive model. And GoPro, the category leader with about 13.7 million cameras sold in six years, installed a faster processor and increased shooting speed from 15 frames per second to 30. Whether you're a daredevil looking for hi-res glory and crash-proof durability or a lifelogger demonstrating wine-tasting skills, there's an action camera for you. **MICHAEL NUÑEZ**



**How can I keep
my phone, network
and number for
half the cost?[†]**

**Connect the dots
to find out.**

1 ●

2 ●

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wireless

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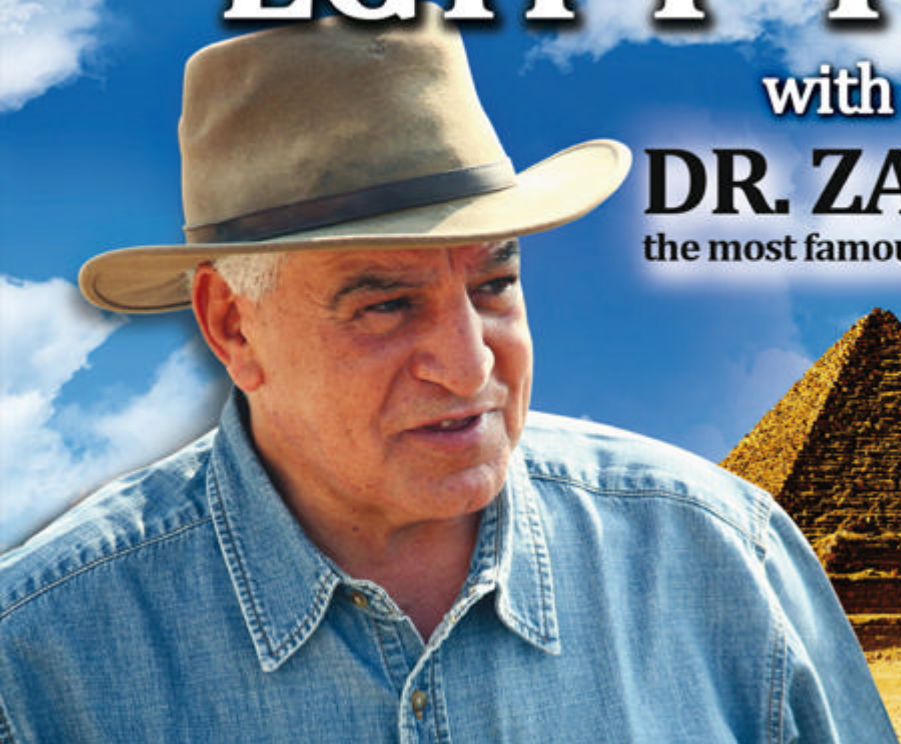
[†]"Half the Cost" is based on a service comparison of the two largest contract carriers' monthly online published prices for comparable individual contract plans and the Straight Talk Wireless 30-Day \$45 Unlimited talk, text and first 3 GB of high-speed data service plan, excluding the cost of the phone, additional fees and limited time promotions. Source: Contract carriers' websites, January 2015. Straight Talk reserves the right to terminate your service for unauthorized or abnormal usage. Please refer always to the latest Terms and Conditions of Service at StraightTalk.com.

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Group photo - November 2014 Egypt tour with Dr. Zahi Hawass.

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Teeth barely longer than the diameter of a human hair allow limpets to scrape food from rocks.

EDITED BY **Jen Schwartz & Breanna Draxler**

Next



Spider silk had a good run as nature's strongest material. But recently, limpet teeth—made of mineral nanofibers—were found to be up to five times stronger. Asa Barber, an engineering professor at the University of Portsmouth in England, measured the stretching force needed to break the aquatic snail's teeth and says they're comparable to man-made carbon fiber, only more flexible. "We can take these features we see in nature into the lab," he says, "to help drive better designs for planes and cars." **JUNNIE KWON**

Jess Peláez

On blueprinting Earth's ecosystems



Restoring environments after human intrusion or natural disasters is complicated: There's still much we don't know about the interplay of microbes and mammals, aquifers and air pollution. But geologist Jess Peláez thinks the solution is as simple (and as complex) as cataloging our ecosystems, one at a time.



"We want to hand off this project to the next generation—like a seed bank for environments."



When humans extract resources like trees and coal, repairing the damage is often limited to 'Let's throw some dirt in a hole.' That's partly what inspired me to start the nonprofit Blueprint Earth. We want to lay the groundwork for a much higher standard. Even though we understand that everything in nature is interconnected, science has become so specialized that no one really knows how to put a complete environment back together. The goal is to combine the work being done in individual disciplines—from the granular to the macro level.

In our first project, we're working with scientists, engineers, and students to catalog one square kilometer of the Mojave Desert. We're creating a blueprint of the geology, biology, hydrology, and atmosphere to understand how they all interact. Once we've mapped the data, we'll test our blueprint by re-creating that section of desert—the spring, the toads, the fungi—in a giant warehouse nearby. The know-how exists; scientists are already simulating geologic features, like landslides and lava flows, in labs. We're never going to be quite as good as Earth itself, but let's figure out how close is close enough.

The initial purpose is to make something functional. Take a place damaged by deforestation, like Haiti. We could blueprint an analogous area of the Dominican Republic, which is healthy, and try to replicate it in Haiti to help the environment heal in a way that isn't possible now.

Further down the road, we hope our data will be useful for space exploration and help programs like NASA and SpaceX do optimized terra-engineering. Something this big-picture can seem terrifying, but when it's framed as a collaboration over many lifetimes, it's not."

AS TOLD TO KATHERINE KORNEI

18,000,000

Estimated number of acres world-wide lost annually to deforestation

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An Elevator That Will Reshape Skylines

With the debut of passenger elevators some 150 years ago, cities were forever changed. Freed from the tyranny of stairwells, architects built as high as they liked. That is, until they ran into another barrier: the weight of steel cables. A new elevator design from German company ThyssenKrupp may solve that problem by trading cables for tracks that employ magnetic levitation, or maglev. Unconstrained by a linear pulley system, the cars—to be tested in Germany next year—will travel higher and in new directions, moving horizontally and even diagonally. The system, called Multi, may help make possible buildings of unprecedented size and energy efficiency, like this conceptual Edison Tower.

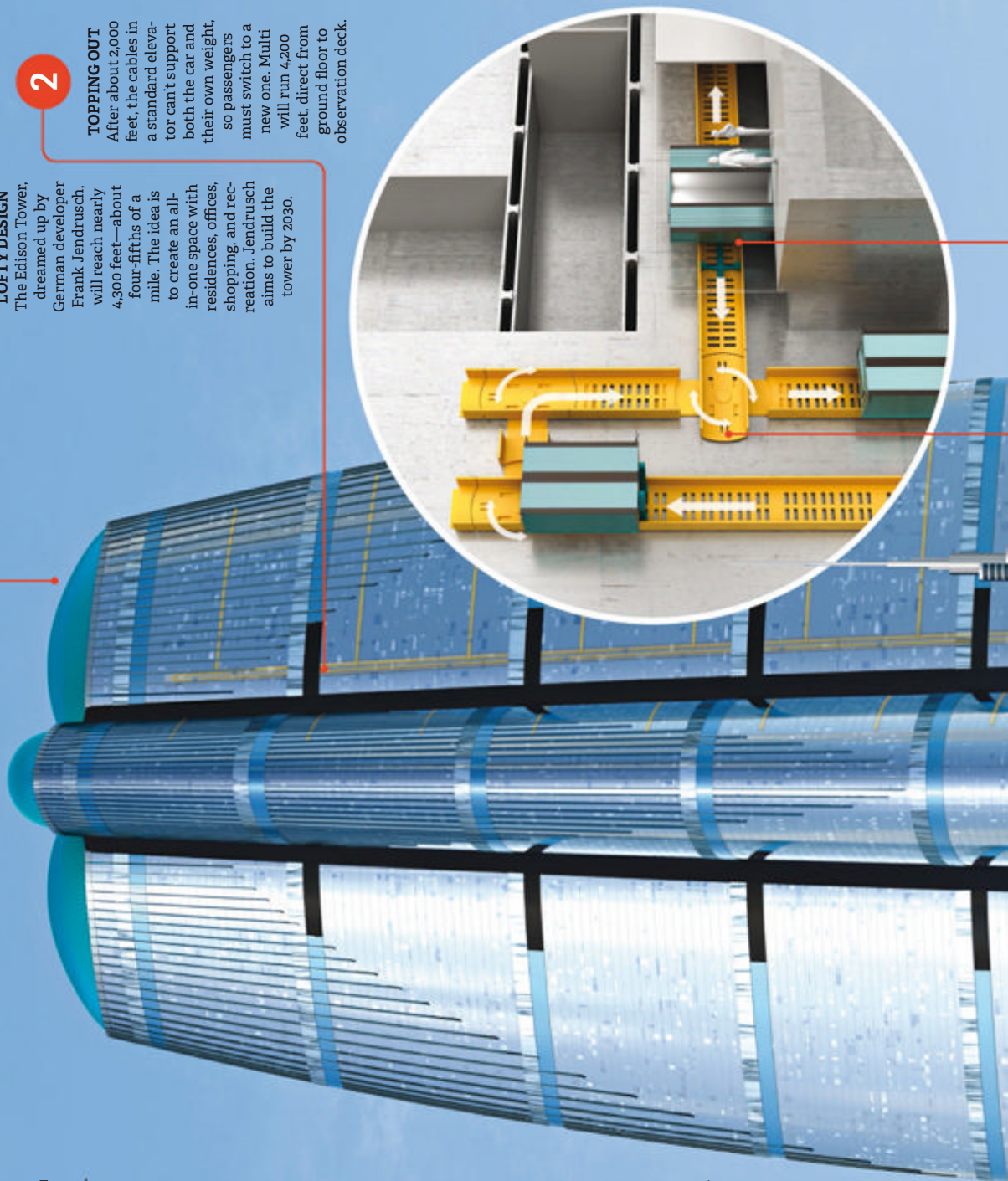
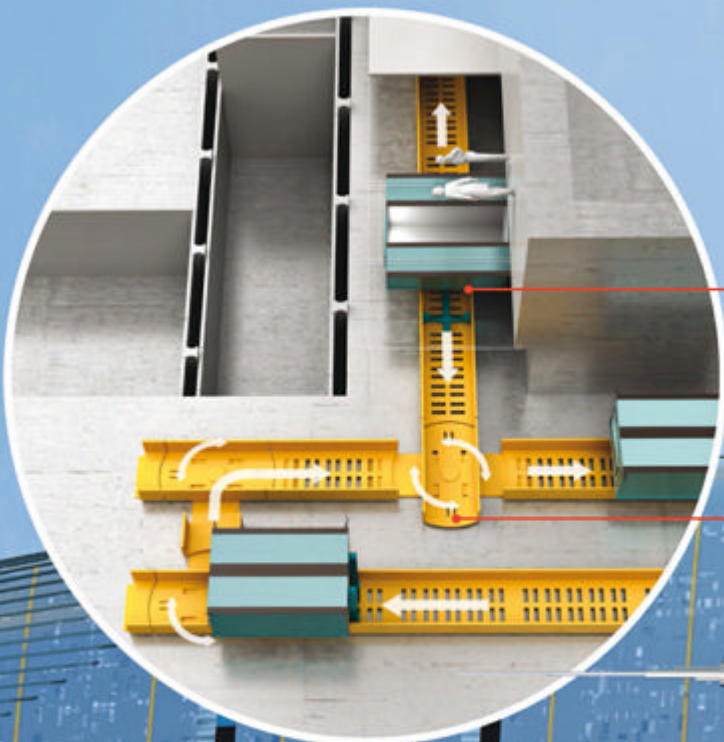
Patrick Bass, CEO of ThyssenKrupp North America, says supertall, power-producing skyscrapers could help accommodate booming urbanization. **LOREN GRUSH**

LOFTY DESIGN

The Edison Tower, dreamed up by German developer Frank Jendrusch, will reach nearly 4,300 feet—about four-fifths of a mile. The idea is to create an all-in-one space with residences, offices, shopping, and recreation. Jendrusch aims to build the tower by 2030.

1

TOPPING OUT
After about 2,000 feet, the cables in a standard elevator can't support both the car and their own weight, so passengers must switch to a new one. Multi will run 4,200 feet, direct from ground floor to observation deck.



3

MAGNETIC PULL

Multi will enable Maglev to "float" to its destination. Magnets in the car will repel opposing magnets along the track, causing the car to hover. A separate set of coils along the track will push and pull the car in its intended direction.

4

RANGE OF MOTION

Multi is far more nimble than a pulley system. To change orientation, the section of rail carrying the elevator car will rotate, shifting the direction of the moving magnetic field.

7

ROOM TO GROW

Up to 20 percent of any high-rise building is consumed by elevator space. ThyssenKrupp estimates that Multi could reduce the elevator footprint in future buildings by up to 50 percent.

Burj
Khalifa,
Dubai,
2,722 ft.

1 World
Trade
Center,
New York
City,
1,776 ft.

6

POSITIVE ENERGY

With its unique star shape, the core of the Edison Tower will act similarly to a solar updraft tower, using the flow of hot air to turn internal turbines. Along with photovoltaics, it'll produce power for the building.

8

SPRAWLING FOOTPRINT

The building will cover nearly one square mile.

5

OUTDOORS IN

All that additional space will allow for creative interior designs, like parks.



By the Numbers

CRAFT BEER IS ANNIHILATING THE HOP SUPPLY

Even the diviest bar's tap list will tell you: The craft beer boom is upon us. In 2014, the U.S. was home to 3,200 craft breweries; this year, a new one will open every 16 hours. The trend is a boon for adventurous drinkers, but it's stretching the hop supply dangerously thin.

"The demand is unprecedented," says Steve Miller, hop specialist at Cornell University. Hop consumption has nearly quadrupled in the past decade, thanks in part to the popularity of super-hoppy India Pale Ales, which now account for more than a fifth of the craft beer market.

Washington's Yakima Valley, a hotspot for domestic hop producers, can't keep up, so single-acre hop operations are popping up on other types of farms across the country. Growers in New York, Minnesota, and Colorado provide local brewers with hops that reflect a distinctive regional terroir. In return, many brewers agree to share up-front costs, guaranteeing a market for the harvest.

"The locavore movement has gone beyond the salad bowl to the pint glass," says Tom Britz, founder of Glacier Hop Ranch, which supplies 18 Montana breweries. This new, more diverse model may buoy the rapid rise of craft breweries. And a sustainable supply of pumpkin peach ale is something we can all drink to. **MATT GILES**

132

Number of hop varieties used by U.S. brewers, up from 88 in 2009

POUNDS OF HOPS USED BY U.S. CRAFT BREWERS ANNUALLY

31 MILLION (PROJECTED) IN 2015

27 MILLION IN 2014

"Craft brewing is sucking up every pound of hops in the U.S. Growers can't expand fast enough."

—Doug MacKinnon, former director of the Hop Growers of America

6 MILLION IN 2007

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IS IT TIME FOR US TO PHONE E.T.?

In our search for extraterrestrial intelligence (SETI), we humans have mostly just waited, and listened, for aliens to contact us. But in February, policymakers, philosophers, futurists, and astronomers convened to debate a new approach: contacting aliens directly.

Initiating active SETI is no small decision. Sure, we've tacked messages onto the occasional space probe, but transmitting detectable signals to habitable zones hundreds of light-years away requires commitment. Operating the Arecibo telescope's radar for a year would run up a bill of some \$2 million; future, more powerful broadcasters will suck up even more energy. Plus, we may signal for thousands of years before we reach anyone, and it could take just as long to get a response.

Some astronomers fear announcing our existence may attract the attention of civilizations bent on destroying Earth or mining its minerals. It's a point Stephen Hawking has argued before: "Advanced aliens would perhaps become nomads, looking to conquer and colonize whatever planets they can reach." John Gertz, former chairman of the board at the SETI

Institute, suggests banning contact altogether. "You're going to risk the entire fate of the planet just to get a conversation going?" he asks.

The fact is, TV and radio transmissions have long been leaking into space, weakly pointing to life on Earth. We don't know whether life is even out there, let alone whether it wields laser blasters. Adam Korbitz, an attorney specializing in SETI, argues there could be more danger in remaining a wallflower: "Our long-term survival may depend on joining the galactic club." Advanced civilizations might have engineered a way out of climate change or cracked the code on quantum physics.

If we hold off, we may miss an opportunity to understand the mysteries of the universe—or at least learn that we're not alone. It's time we make the first move. SARAH SCOLES

HOW WE COULD TALK TO ALIENS TODAY

1 Blast a laser that will outshine the sun for a nanosecond so it can't be missed.

2 Broadcast the whole Internet, which is redundant enough to be self-decoding.

3 Ping habitable planets with powerful and targeted (but content-free) radio beacons.

4 Compose messages of electromagnetic waves that are intelligent, if unintelligible.





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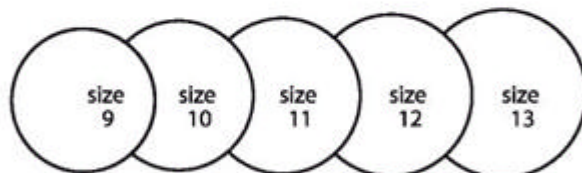
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Ring Size Chart



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THE 2015 **Invention Awards**



It took a whole team to build a 3-D portrait of Bre Pettis. Artist Sophie Kahn scanned his head. Then, MakerBot designers Nathan Worth, Lane Feuer, and Anne Miner cleaned up the scans and digitally modeled a mechanical brain. Finally, they printed the parts on a MakerBot Replicator Z18, painted them, and assembled Pettis's plastic double. Why? Because they could.



How to Be a (Brilliant) Inventor

WITH BRE PETTIS



As the co-founder of MakerBot Industries, Bre Pettis launched the first affordable 3-D printer, bringing the power of rapid prototyping and micro-manufacture into homes and workshops around the globe. While the rest of us catch up, Pettis has already moved on. At Bold Machines, the skunkworks he founded, he helps other inventors bring ideas to life. Pettis explains why invention has never been easier.

How did you come up with MakerBot?

We wanted a 3-D printer, but we couldn't get our hands on one. So we just had to try and try again until we made one that worked. The core of innovation is trial and error. Fail as many times as it takes, and be strategic about what you learn.

What makes an invention groundbreaking?

So many inventions are solutions for problems that don't exist. Actual innovation is really hard, because you have to project yourself into a future that hasn't been invented yet. And often, when you think of something that changes the paradigm or is disruptive, there are all sorts of reasons you shouldn't do it. You have to stick your fingers in your ears and pretend those reasons don't exist.

How do you know whether you'll succeed?

Maybe you don't! That's why it is, in general, a horrible idea to be an inventor. You have to be willing to risk years of your life.

Do you recommend working with others?

There are a few different

variations of inventor. Are you an entrepreneur? An engineer? A researcher? A visionary? I think you need all those things on your team to actually get an invention invented and out in the world. Or you can be a couple of people wearing multiple hats.

What kind of inventor are you?

I'm a little bit of a weirdo. My primary mission is to empower people to be creative. I wish I could say I was a brilliant technical mind, but my real superpower is being a visionary and gathering together exceptionally talented people who get wonderful things done.

It sounds difficult to create something truly new, at least for those of us without superpowers.

It has never been a better time to invent things. It used to be you had to be a tycoon with a factory and a big R&D department. Now, basically anybody can buy a Raspberry Pi or a microcontroller and a bunch of sensors and be on their way. Then, when you have to add code, you can probably modify somebody else's: The software is accessible. And the Internet—there are so many things that people have shared that you can take inspiration from and modify and mess with. We live in a much more connected, fantastic, collaborative world today.

If you could give aspiring inventors one task, what would it be?

Begin.

And one thing to avoid?

Don't stop.

EDITED & CONDENSED BY
SOPHIE BUSHWICK

Invention Awards

AVIATION

A Plane That Folds Into a Car



1

The adjustable wing can optimize its angle of attack for taking off or cruising. This allows for reduced speed and distance during takeoff.

2

Light materials, including a carbon-composite body over a steel airframe and six-pound carbon wheels, keep weight low.

3

The prototype's 100-horsepower four-cylinder Rotax 912 engine runs on conventional gasoline, so drivers can fuel up at existing gas stations. (Production models may have a different engine.)

4

A robust suspension will enhance on-road performance and enable takeoff and landing on relatively rough terrain.



After Czechoslovakia's communist regime fell, in 1989, designer Štefan Klein began working on a concept for a flying car. Inspired by his newfound freedom, he aimed to translate that personal liberty to the skies. In 2010, he shared his work with his friend Juraj Vaculík, an entrepreneur. They joined forces to found AeroMobil and develop a viable commercial product. "We wanted to create a car and airplane without compromises," Vaculík says, "to provide individuals with a new, interesting option for door-to-door personal transportation."

Others have attempted and failed to build flying cars. But AeroMobil isn't a car that can fly; it's an airplane that can drive. Its light weight, collapsible wings, and efficient design make it precision-tuned for flight. On the ground, it provides roadster-like handling.

Last October, Klein drove the fourth prototype, AeroMobil 3.0, to a grassy airfield in Nitra, Slovakia, unfolded its wings, and took off on the vehicle's maiden flight. It soared in a 12-mile circle more than 800



Inventors:
Štefan Klein and
Juraj Vaculík

Company:
AeroMobil

Invention:
AeroMobil

**Development
cost to date:**
Undisclosed

Maturity:
◆◆◆◆◆

feet off the ground and landed back at the same airfield. Since then, AeroMobil has completed more than 40 test flights. The company is now pursuing an airworthiness certification with the Slovak Federation of Ultra-Light Flying to permit expanded flight testing throughout the European Union. Meanwhile, further structural and aerodynamic tests will help finalize the vehicle's design.

Because the U.S. has stringent vehicle-safety regulations, the current prototype is intended for countries with more flexible road rules. The AeroMobil team hopes it will be classified as a light-sport aircraft, which requires a pilot's license. Future models may inspire their own class. "At the beginning, we'll need certification for both airplane and car," Klein says. "But this truly is a new category." **ERIC ADAMS**

MEDICINE

Needle-Free Vaccination



Vaccines save lives, but most of them are delivered by needle. That's a problem for people without access to refrigerated solution, clean syringes, and safe ways to dispose of medical waste. Biomedical engineer Kasia Sawicka invented a painless alternative: a patch, called ImmunoMatrix, that can vaccinate patients without breaking the skin. "This technology can affect how vaccines are delivered, especially during pandemics," Sawicka says.

The skin doesn't absorb large molecules easily, which meant Sawicka had to find another way to get vaccines across that barrier. As an undergraduate at Stony Brook University, she worked in a lab that stocked an extremely water-absorbent material called poly-vinylpyrrolidone. She found that this polymer (used in hairspray during the era of beehive hairdos) could pull water out of the skin. When moisture returned, the outer layer of the skin swelled, allowing larger-than-usual molecules to enter.

Over several years, Sawicka perfected a process that involves combining the polymer with vaccine solution, forming it into nanofibers with large surface areas, and weaving those fibers into dense mats. In tests on rats and synthetic human skin, the patches delivered vaccine

molecules 250 times larger than those the skin typically absorbs. No prick necessary.

ALEXANDRA OSSOLA



Inventor:
Katarzyna "Kasia" Sawicka

Company:
ImmunoMatrix LLC

Invention:
ImmunoMatrix

Development cost to date:
\$100,000–200,000

Maturity
◆ ◆ ◆ ◆ ◆

Special packaging lets the patches go without refrigeration for 10 weeks, far longer than vaccine solution.



5 Avionics from Garmin will include a two-axis autopilot to control pitch and roll. In case of emergency, the vehicle will have a ballistic parachute safety system.

BRE'S ADVICE



TIP #1

Be an early adopter. Try buying a bitcoin. Set up a Raspberry Pi as an arcade machine. Doing things gets the juices flowing and gets you thinking in new ways.

Invention Awards

COMMUNICATION

A Braille Printer Born From LEGO



The world's cheapest Braille printer got its start with a single piece of mail. Upon seeing a letter soliciting donations for the blind, Shubham Banerjee, then 12 years old, asked his parents how blind people read. They suggested he Google it. Banerjee's Internet search turned up Braille printers, all of which cost more than \$1,800. So he set out to make a cheaper alternative using his favorite toy—LEGOs.

Banerjee finished building his first prototype, Braigo, in February 2014. But the device was limited to printing on narrow rolls of paper. "I still love LEGO, but I had to move on to something that would be released into the market," he says.



Inventor:
Shubham Banerjee

Company:
Braigo Labs Inc.

Invention:
Braigo

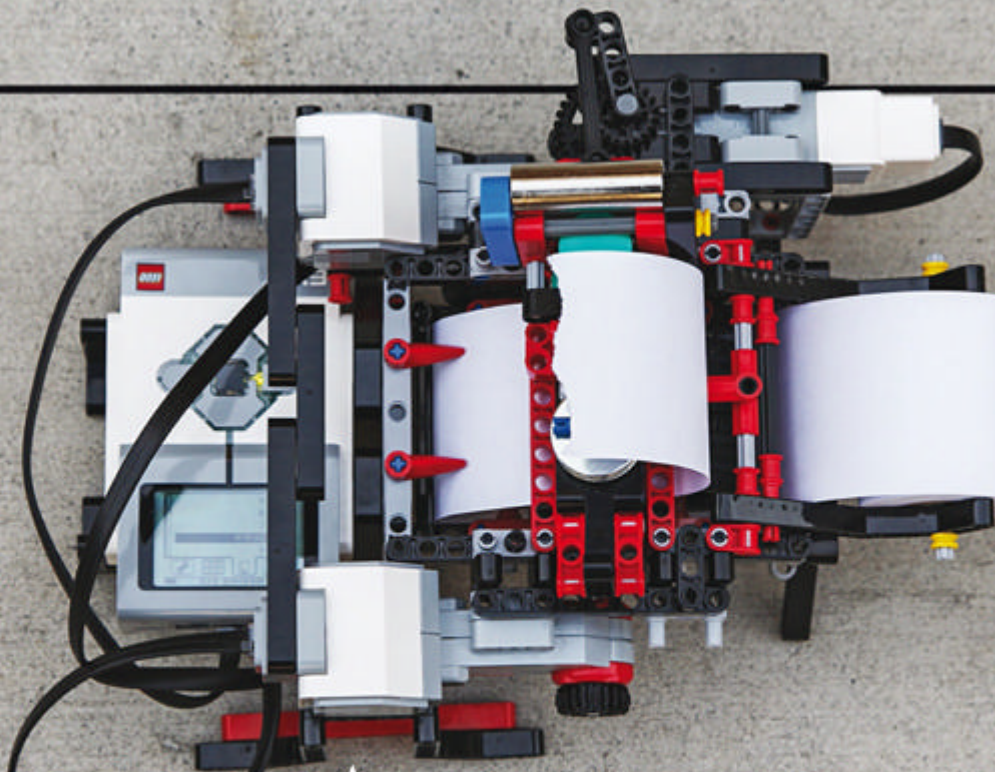
Development cost to date:
Undisclosed

Maturity:
◆◆◆◆

In summer 2014, Banerjee formed Braigo Labs with the help of his parents. That fall, he released the prototype for Braigo 2.0 at the Intel Developer Forum, and Intel Capital offered him seed funding for further R&D. Along with a team of advisers, Banerjee, now 13, is currently refining the second iteration of his printer, which will consist of

fabricated printer parts powered by an Intel Edison chip.

Like its predecessor, Braigo 2.0 is light and portable—but it's far more advanced. Using both Wi-Fi and Bluetooth, its chip will connect the printer to a webpage where users can type standard text. Braigo will automatically translate the words into Braille, converting a 160-



The first version of Braigo, built with parts from a LEGO robotics kit, used a thumbtack to punch Braille dots into paper. Banerjee put the design and software for Braigo 1.0—which costs about \$355 to make—online for free.

WEARABLES

Personal Pollution Monitor



Journeyman electrician Kevin R. Hart and nurse Laura Moe are the type of people who attend Environmental Protection Agency events for fun. They're also the

A fan directly beneath TZOA's triangular cover sucks in air. As pollutants cross a laser, they scatter light onto a sensor that counts them. TZOA then glows a color corresponding to the air safety level. A smartphone app also displays that data, along with daily UV light exposure and crowdsourced pollution maps.



Inventors:
Kevin R. Hart and Laura Moe

Company:
TZOA Wearables

Invention:
TZOA

Development cost to date:
Undisclosed

Maturity:
◆◆◆◆◆◆

type who leave an event, as they did in 2013, determined to help solve the planet's single largest environmental health risk: air pollution. Most cities rely on just a handful of expensive air monitors to detect hazardous pollution levels. Hart and Moe decided to build a wearable device that collects data everywhere a person goes.

After planning out how the sensor would work, the pair turned to the resources at MakerLabs, a community workspace in their native Vancouver, British Columbia, for further development. "We used basically everything in the building," says Hart. A group of physicists renting space on the top floor worked with them to build an accurate air pollution monitor

BRE'S ADVICE

TIP
#2

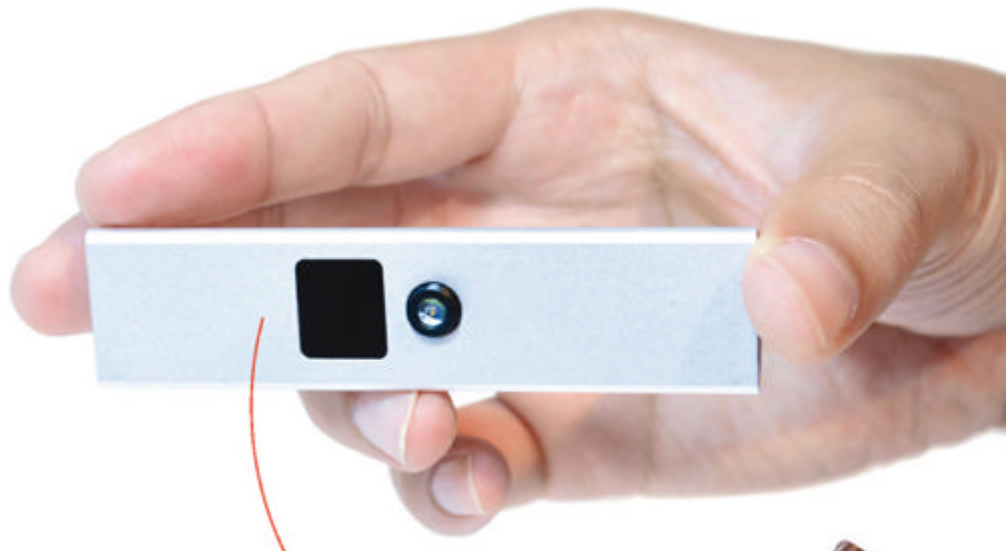
Seek out mature industries—ones that haven't been automated or touched by the Internet. Disrupt them by making things networked, better, and more affordable.

page document in 35 seconds.

Once printers are ready, they will be sent to various institutes for the blind for testing and feedback. The final model, planned for release in late 2015, will sell for less than \$500, making it the first—and only—low-cost Braille printer. **ALLIE WILKINSON**

smaller than anything on the market. Industrial designer Afshin Mehin helped make the device beautiful. The size of an Oreo cookie, the sensor measures particulate matter, a key air pollution component, as well as ultraviolet light.

Hart and Moe plan to sell TZOA, as they named the monitor, for \$99, in late 2015. Citizen-scientists want the sensors to pinpoint polluters, but Hart sees bigger potential for individuals who want to protect their health. Using data from TZOA, parents can keep infants away from pockets of pollution, and athletes can plan workouts for the least-polluted routes and times of day. **MADLINE BODIN**



Nimble Sense could let VR users grab and throw a digital object or even pluck the strings of a virtual guitar.



Inventors:
Robert Wang,
Chris Twigg,
Kenrick Kin, and
Shangchen Han

Company:
Nimble VR

Invention:
Nimble Sense

**Development
cost to date:**
Undisclosed

Maturity:
◆◆◆◆◆

GAMING

Hands-On Virtual Reality



When peering through a virtual-reality headset, players can't see their hands—or use them to interact with their digital surroundings. To solve VR's interaction problem, software developers Robert Wang, Chris Twigg, Kenrick Kin, and Shangchen Han formed a start-up, courted investors, and got to work.

The four had spent years working with motion-tracking camera systems and developing algorithms that monitor and analyze skeletal structure. With their experience, it didn't take long to craft software that tracks joint angles and knuckle placement to create realistic virtual hands. But they couldn't find a camera sensitive enough to pick up such data. "We played with them all," Wang says. "There was no

depth-sensing camera good enough for VR hand tracking." Existing videogame motion trackers, such as Microsoft's Kinect, are designed to detect large objects, such as a bouncing 8-year-old several feet away, not subtle hand movements.

The team set out to design its own specialized camera, Nimble Sense, small enough to fit over an Oculus headset and with a field of view optimized for VR. It monitors users' hands, and software then digitally mimics every gesture. Facebook-owned Oculus VR was so convinced it bought the start-up, Nimble VR, last December. Now, the developers are working to make Nimble Sense even better. "There are still a lot of interesting problems left to be solved," Wang says. **MO MOZUCH**

Invention Awards

AUTOMOTIVE

A Self-Balancing Vehicle



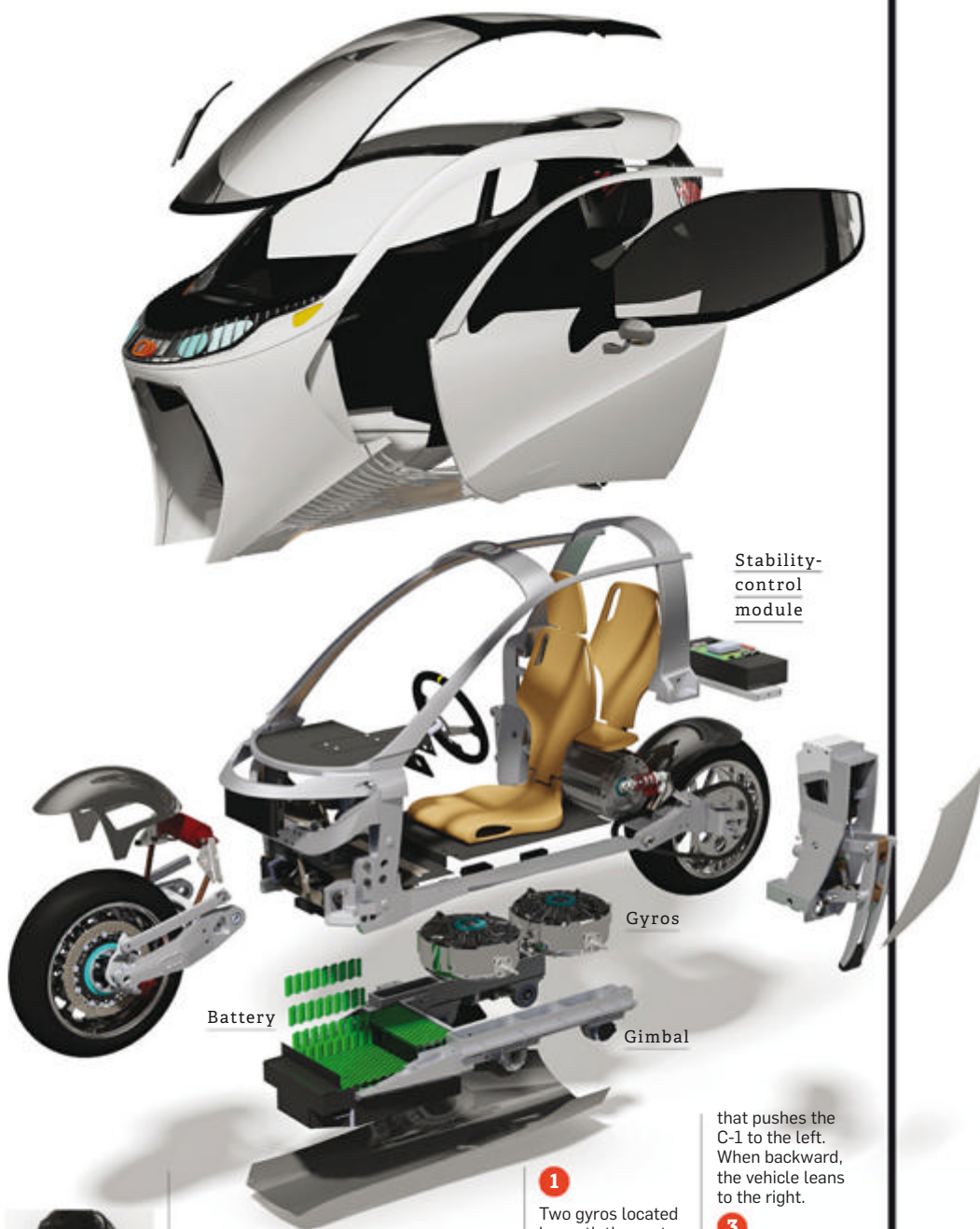
Daniel Kim thinks most commuters drive around in way too much car. For single-passenger trips, motorcycles are much more fuel-efficient—a critical feature in an era of climate change—but they are also more dangerous, expose riders to the elements, and require skill to keep upright. Kim's solution? Cut the car in half.

His all-electric C-1 prototype has two wheels, like a motorcycle, but a steel, aluminum, and composite outer body, like a car. It can even drive backward. If you sit inside the C-1 and sway from side to side, a gyroscopic control system keeps the vehicle upright. "When was the last time you balanced on a motorcycle at zero miles an hour?" Kim asks rhetorically. "Never."

A two-time college dropout, Kim hatched his idea in 2004, while running a business customizing cars. That's when he narrowly missed being crushed under the 500-pound chassis of a Land Rover. He emerged with the conviction that no single person needs such a large vehicle. Kim went back to college and graduated from the Rhode Island School of Design. Then, concept in hand, he raised \$3.5 million in venture capital—enough to launch Lit Motors in 2010.

The allure of a self-stabilizing two-wheeler has tempted automotive designers for at least a century. Earlier attempts, however, had fatal flaws—the gyros were too large, the mechanical control systems too crude. The C-1 instead employs computer-directed control-moment gyros, the same tools currently steering satellites in space.

Kim says the finished vehicle



Inventor:
Daniel Kim

Company:
Lit Motors

Invention:
C-1

Development cost to date:
\$3.5 million

Maturity:
◆◆◆◆◆

should go from zero to 60 miles per hour in six seconds or less, reach a top speed of 100 miles per hour, and enjoy a 200-mile range. He hopes the product will hit the market within two years but admits that the challenge is substantial. "There is no real academic track for learning how to start your own car company," Kim says, "so I had to make it myself." **JAMES VLAHOS**

1

Two gyros located beneath the seat whirl clockwise at 5,000 to 12,000 rotations per minute. Like any rapidly spinning disc, such as an airborne Frisbee, the rotors naturally stay level.

2

Single-axis gimbal assemblies, which hold the gyros, can tilt forward and backward. When tilted forward, the gyro generates a powerful torque

that pushes the C-1 to the left. When backward, the vehicle leans to the right.

3

The computerized stability-control module changes the tilt of the gimbals to keep the C-1 balanced. The vehicle remains level when driving straight or standing still and leans at an angle when making turns.

4

A 10.4 kilowatt-per-hour battery pack lasts 150 to 200 miles on a single charge.

1

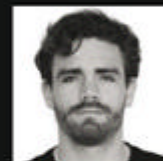
The ceramic outer shell has a chemical makeup similar to that of coral, which encourages polyps to take root. Its textured surface gives smaller organisms places to hide from predators.

2

Concrete, reinforced by composite rebar, gives the reef a durable core. These materials can last at least 60 years underwater.

3

The open shape allows strong currents to move through the reef without knocking it over. The structure also traps eddies, which carry the nutrients that feed marine organisms.



Inventor:
Alex Goad

Company:
Reef Design Lab

Invention:
Modular Artificial Reef Structure

Development cost to date:
\$11,500

Maturity:
◆◆◆◆◆

ENVIRONMENT

An Artificial Reef for Any Seafloor



During a 2011 trip to Miami, Alex Goad went scuba diving and explored the artificial coral reefs off the Atlantic coast. Such reefs, he realized, are large, heavy, and expensive to fabricate and install. But they serve an important purpose. Natural coral reefs are some of the most biodiverse places on Earth, and they've begun to disappear, leaving thousands of species

essentially homeless. Building up artificial reefs where real ones have been lost is one stopgap solution.

So for his final project as an industrial-design student at Monash University in Melbourne, Australia, Goad created the Modular Artificial Reef Structure (MARS). Locking and clamping mechanisms on the arms of each MARS unit allow them to snap

together easily, like LEGOs. The modular structure makes MARS more flexible than other artificial reefs. "A lot of existing products require a flat seafloor. But around the world, the ocean is not flat, especially where reef systems occur," Goad says. "With MARS, you can build over natural features, as high and as wide as you want."

After graduation, Goad teamed up with his adviser David Lennon, the director of Sustainable Oceans International, to found Reef Design Lab and make MARS a real home for marine life. It took between 10 and 15 prototypes to find the ideal materials, surface texture, size, and weight for the units, which they tested in aquariums and in Australia's Port Phillip Bay. Goad and Lennon plan to release MARS this fall for purchase by environmental organizations and coastal communities. "When local communities physically build the artificial reef, they gain a greater appreciation for natural reef systems," Goad says.

LINDSEY KRATOCHWILL

BRE'S ADVICE



TIP #3

Embrace the absurd. Everything we take for granted now was weird when it first came out. While building your automated pinball-machine cocktail-serving robot, you may just discover something truly innovative.

Invention Awards

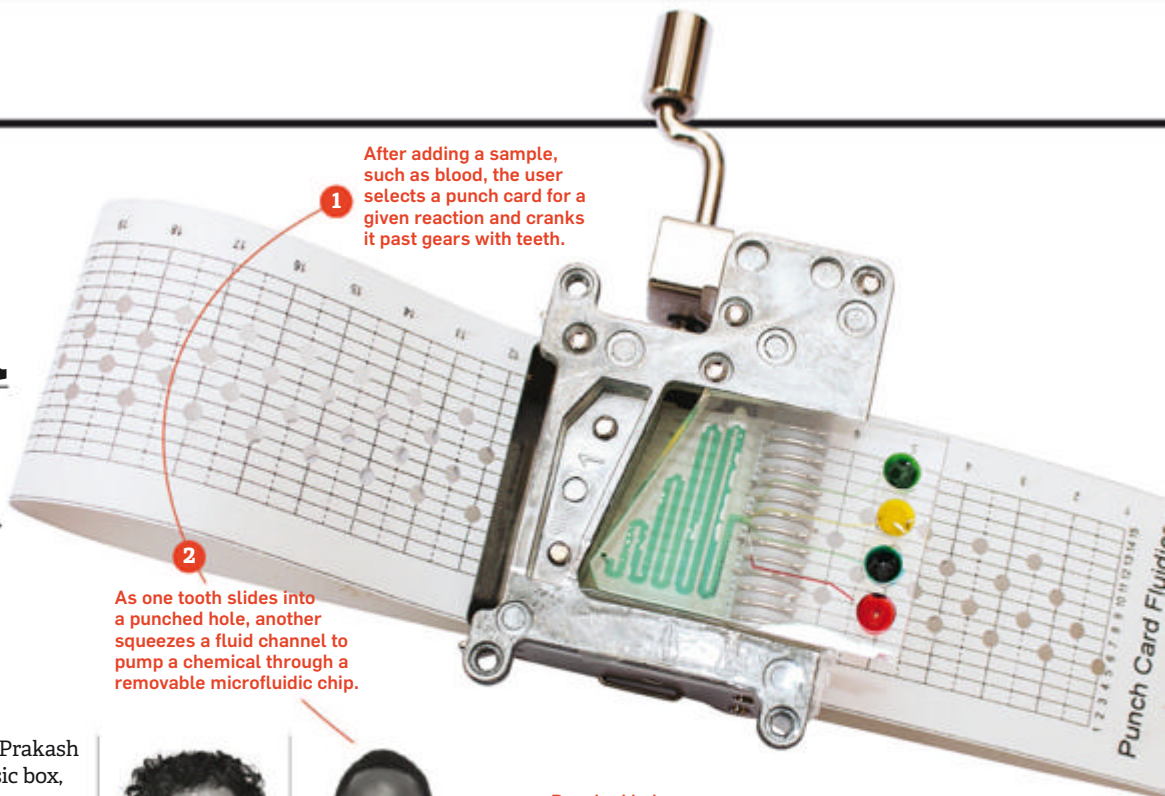
HEALTH

Medical Lab in a Music Box



One night in 2011, as Manu Prakash turned the handle on a music box, he realized the simple mechanism—a crank rotating gears—could also run a programmable chemistry set. Most “lab-on-a-chip” devices require computers, technicians, and expensive laboratories to pump precise amounts of liquid through a microfluidic chip. But a hand-cranked mechanism could eliminate all that; Prakash’s idea wouldn’t even need power. “What we’re doing here is steampunk chemistry,” he says.

Prakash, who heads a Stanford University research lab, recruited graduate student George Korir to help create a sophisticated scientific



1 After adding a sample, such as blood, the user selects a punch card for a given reaction and cranks it past gears with teeth.

2 As one tooth slides into a punched hole, another squeezes a fluid channel to pump a chemical through a removable microfluidic chip.

3 Punched holes can also trigger the release of a single droplet, for precise volume control.

4 Up to 15 different chemicals react with one another as they travel along channels etched on the chip.



Inventors:
Manu Prakash and George Korir

Affiliation:
Stanford University

Invention:
Punchcard Programmable Microfluidics

Development cost to date:
\$50,000

Maturity:
◆◆◆◆◆



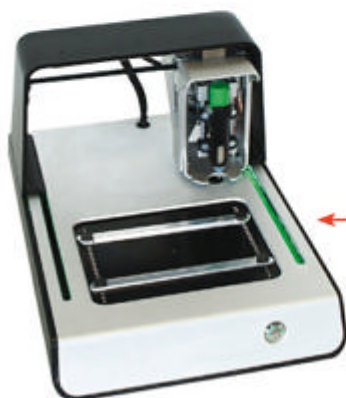
device that works like a music box. First, the duo had to figure out how paper punched with patterns of holes—each keyed to a different chemical reaction—could activate tiny mechanical pumps and valves to generate nanoliter droplets. Twenty-some prototypes later, they’re preparing their apple-size invention, Punchcard Programmable

Microfluidics, for mass production. While conventional microfluidic pumps can cost \$1,500 each, Prakash says this device, which contains 15 pumps, will run \$5.

Relatively simple to use, the instrument will enable anyone with a chip and a hole punch to perform a complex chemical reaction, such as diagnosing disease from a blood

ELECTRONICS

A Printer for Circuit Boards



While studying mechatronics at the University of Waterloo in Ontario, Alroy Almeida, Jesus Zozaya, and James Pickard became frustrated by the inefficiency of designing

One print head deposits a custom-formulated, highly conductive silver nanoparticle paste. Another extrudes insulating ink to form layers of circuitry without risking electrical shorts. Solder paste from a third print head can attach components, such as resistors or microcontrollers, to the board.



Inventors:
Katarina Ilic, Alroy Almeida, Jesus Zozaya, and James Pickard

Company:
Voltera

Invention:
V-One

Development cost to date:
\$200,000

Maturity:
◆◆◆◆◆

circuit boards. “We’d spend a couple hundred dollars to get prototypes made at a factory and wait a few weeks, and they would come in and be wrong,” Almeida says. After they revamped the design, the agonizing process would begin again, sometimes through multiple prototypes.

Meanwhile, they watched as 3-D printers rapidly prototyped other kinds of products. An inkjet printer that deposited circuits would speed up electronics design—but conduc-

BRE'S ADVICE

TIP
#4

Invent things that make people's lives easier, safer, or more creative. Explore big problems—what could you invent to get me from New York City to London in 15 minutes? Explore small problems—what would it take to manufacture nano-scale ball bearings?

5 The user examines the results via embedded lenses that magnify images hundreds of times.

sample. Even lightly trained medical providers in rural areas and developing countries could identify, and thus control, fatal illnesses. "I grew up in Kenya and saw a lot of preventable suffering," Korir says, "so I'm passionate about getting the right tools to the people who stand between life and death." **ELBERT CHU**

tive material was too thick to squeeze through existing print heads. So when the friends graduated in 2013, they teamed up with nanoscientist Katarina Ilic to build their own device. Two years of R&D later, the team is preparing to ship the V-One to Kickstarter backers.

V-One's swappable print heads lay down conductive circuits on fiberglass boards. By using its solder function to attach components, users can even produce small batches of their devices. Almeida hopes the printer will usher in a new generation of engineers. "This can help people understand that electronics don't need to be difficult." **SHANNON PALUS**

PHOTOGRAPH BY BRIAN KLUTCH;
ALL INVENTOR IMAGES COURTESY INVENTORS



GADGETS

A Frying Pan That Teaches You to Cook



Instead of eating at dining halls in college, Humberto Evans cooked his own meals. His best friend, Mike Robbins, on the other hand, could barely fry an egg. Robbins would forego the lure of takeout only when Evans gave him step-by-step cooking instructions. The two realized that others probably needed some culinary hand-holding as well. With help from two other MIT engineering alumni, Kyle Moss and Yuan Wei, they created the world's first smart frying pan: Pantelligent.

The pan measures its temperature with heat sensors and transmits the data via Bluetooth technology in its handle. A smartphone app uses this information to decide when it's time for a recipe's

next step and then tells the user. "To cook amazing food the way chefs do, you have to build intuition for how long to cook something at the right temperature," Evans says. "We take all that knowledge and package it into our app."

Users can choose a preprogrammed recipe, such as chicken adobo or fried eggs, or select freestyle mode to get temperature readings but not instructions. If a person likes the meal made in this mode, he or she can record and share the recipe. With a tool that de-stresses the kitchen experience, the Pantelligent team hopes more people will skip unhealthy processed meals in favor of home-cooked ones. **JUNNIE KWON**



Inventors:
Humberto Evans,
Mike Robbins,
Kyle Moss, and
Yuan Wei

Company:
CircuitLab Inc.

Invention:
Pantelligent

**Development
cost to date:**
\$20,000+

Maturity:
◆◆◆◆◆

THE RISE of the

EDIBLE!

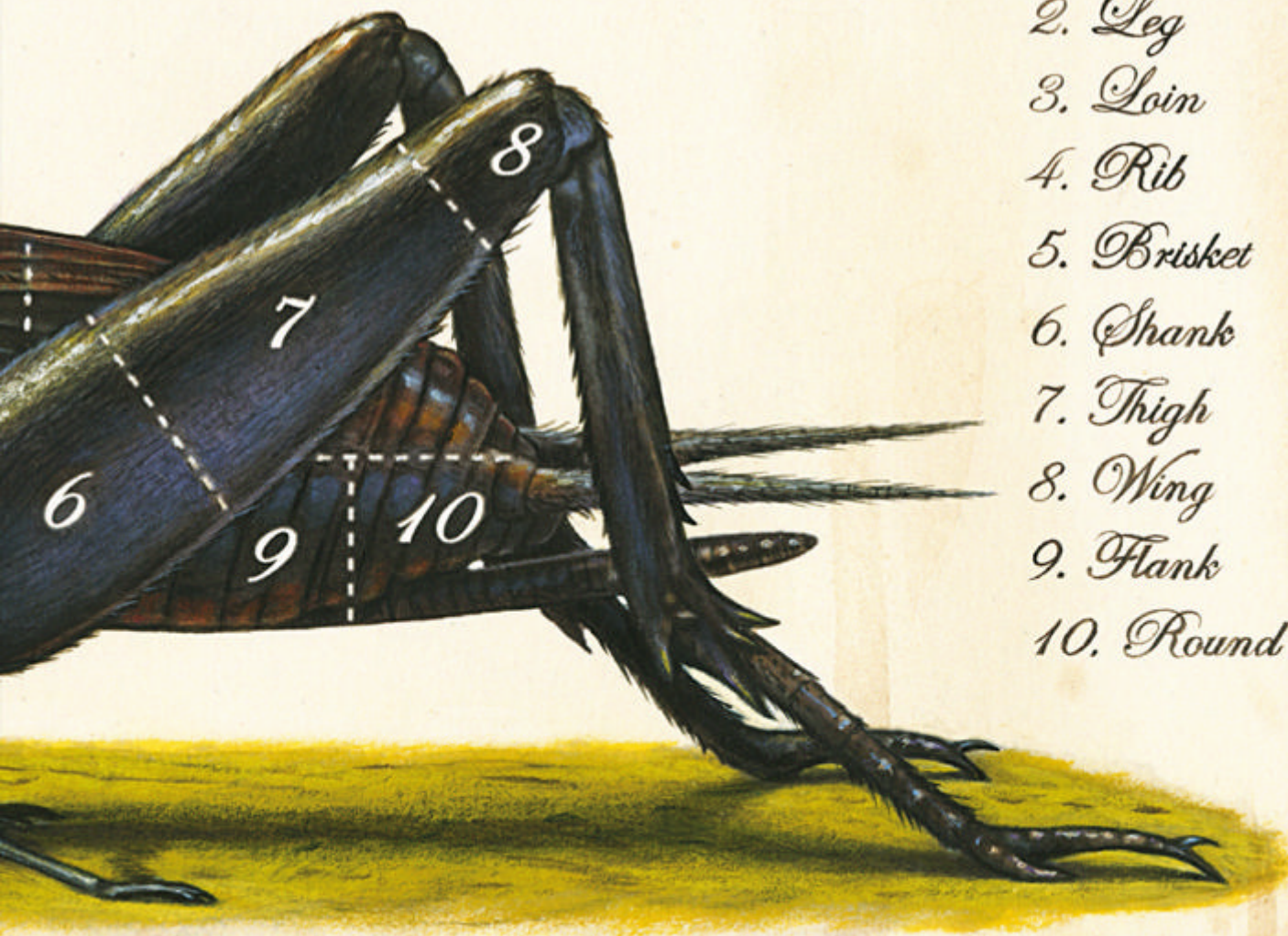
By **BROOKE BOREL**

Illustration by **MARC BURCKHARDT**



INCREDIBLE, INSECT

START-UPS ARE MARKETING AN UNLIKELY NEW PROTEIN. IT'S NUTRIENT-RICH, ALL NATURAL, AND SIX-LEGGED.



1. *Chuck*
2. *Leg*
3. *Loin*
4. *Rib*
5. *Brisket*
6. *Shank*
7. *Thigh*
8. *Wing*
9. *Flank*
10. *Round*



DURING THE LAST WEEKS of winter, in an airy kitchen at the School of Visual Arts in New York City, two design students set about making cocktail bitters. A long wooden table holds mason jars and gleaming bottles of bourbon, vodka, and neutral grain spirits. The fragrance of ingredients that will macerate over the next few weeks, until they surrender their flavor to the alcohol, hangs in the air. There are white bowls of toasted coconut and raw cacao, as well as a jar of cinnamon sticks. Then, there are the crickets.

Lucy Knops rolls up the sleeves of her loose black shirt and carefully pours each ingredient into a small, clear measuring cup sitting on a digital kitchen scale. Her classmate Julia Plevin records the weights in a spreadsheet. When she gets to the crickets, Knops leans closer and peers into the cup. “That’s so crazy,” she says, “there are so many legs!” I follow her gaze; dozens of wiry amputated appendages cling to the sides like the staticky trimmings from a haircut. Knops dumps the whole thing into an empty jar.

I am witnessing a test batch of Critter Bitters, which the pair first created for a school project in 2013. The challenge: make a product in response to a report by the Food and Agriculture Organization of the United Nations (FAO) titled “Edible Insects: Future Prospects for Food and Feed Security.” The report noted that the global population, now at more than 7 billion, may grow to 9 billion by 2050. Already, nearly 1 billion people regularly go hungry. Insects—a source of protein that requires a fraction of the land, water, and feed as livestock—could help alleviate the looming crisis. “The case needs to be made to consumers that eating insects is not only good for their health, it is good for the planet,” the authors wrote. Knops and Plevin figured that while cricket-based bitters might not solve the food problem, the product could help overcome a psychological one. “People are more open to trying new things when there are cocktails involved,” Plevin says.

Most of the world has been comfortable with entomophagy, or the practice of eating insects, for millennia. But it is only in the past few years that it has gained momentum in Western countries, particularly with respect to crickets. More than 30 start-ups specializing in crickets have launched in North America since 2012. A few raise the insects; the rest either sell cricket meal—milled to a fine powder that resembles nut flour—or products made from it, including cricket granola bars, cricket chips, cricket crackers, cricket choco-

lates, and cricket cookies. There are fledgling lines of dog treats too, and one company is working to mash crickets into a paste, the entomophagist’s answer to peanut butter. Late last year, the restaurant consultants Baum and Whiteman forecast that insect protein powder would be among the hottest food and drink trends of 2015, along with oysters, unusual root vegetables, and whiskey.

Critter Bitters abstracts the crickets further, filtering out the evidence rather than grinding it up. In fact, Knops and Plevin suspect that their pure cricket bitters—one of several flavors they plan to offer—may have fewer insect parts than are allowed in food by the U.S. Food and Drug Administration (FDA); cinnamon sticks, for example, may legally contain up to 5 percent insects by weight.

As I watch Knops pour alcohol into the jar of crickets, their bodies bobbing in a rising tide of bourbon, I squint into an older container of bitters—a batch from 2013, the students’ first. It’s now nearly gone. Knops and Plevin never suspected the bitters might become a commercial product, but after they presented their final project to the school, they started getting media attention, including from *Epicurious.com* and *Food & Wine’s* website. “The urge to do something to save a dying planet coincides with a very adventurous time in eating,” says Plevin.

...

North America’s cricket-food industry didn’t spring from a spontaneous, collective epiphany about shifting food tastes. Rather, it can be traced to two catalysts. One was the 2013 FAO report that sparked the birth of Critter Bitters. The other was a 2010 TED talk by Dutch ecological entomologist Marcel Dicke that has been viewed online 1.2 million times. Clicking through PowerPoint slides in an insect-adorned T-shirt, Dicke lays out the case for entomophagy. A burgeoning population will not only add more mouths to feed, he

BAUM AND WHITEMAN FORECAST THAT INSECT PROTEIN WOULD BE AMONG THE HOTTEST TRENDS OF 2015, ALONG WITH OYSTERS AND WHISKEY.

points out, but will require more protein; as people grow richer, they want to eat more meat. Then, there's the economic argument. "If you take 10 kilograms of feed, you can get one kilogram of beef," Dicke says, "but you can get nine kilograms of locust meat. If you were an entrepreneur, what would you do?"

In the U.S., both events rippled through a food culture that is increasingly self-aware, if not always scientific—one populated by gluten-free trendsetters, protein-heavy paleo dieters, and eco-conscious locavores—and through a start-up culture filled with young idealists. "This generation has greater access to knowledge than just 30 to 40 years ago," says David Gracer, a purveyor of exotic arthropods at SmallStock Food Strategies. "And when there are TED talks and FAO reports, they inspire a lot of people."

Thanks to crowdfunding sites like Kickstarter and Indiegogo, aspiring start-ups can now connect directly to an audience especially

receptive to their message. Critter Bitters plans to launch its first Kickstarter campaign this spring, in part to gauge the potential of its customer base. Terry Romero, Kickstarter's food outreach lead, has seen an uptick in insect-food projects. "Instead of the classic investor putting in a giant chunk of money, we are helping companies forge relationships with people who are emotionally invested in what they do," she says. "These will often be loyal fans for years to come."

Crowdfunding has also proved to investors that there's a market to be tapped. Patrick Crowley launched Chapul, the first cricket protein bar in the U.S., with a \$16,065 Kickstarter campaign in 2012. Last year, Crowley was on the reality show *Shark Tank*, where small

businesses pitch to a panel of investors. By the end of the show, Crowley had convinced Mark Cuban, owner of the Dallas Mavericks pro basketball team, to invest \$50,000 for 15 percent equity. And by the end of the year, Chapul had earned nearly \$400,000 from sales both online and in health food stores, food co-ops, and at Central Market, a gourmet chain. This year it will launch in select Whole Foods. "This was really a passion project to spread an idea," Crowley says. "I thought we were probably five to 10 years too early when we launched it; it's happening a lot faster than I had envisioned."

Another success was SixFoods, the creator of Chirps cricket chips, which raised \$70,599 on Kickstarter last year. Now, it's distributing to co-ops in Boston and Seattle and is in talks

THE **NEW!** GROCERY AISLE

Dozens of cricket-food start-ups have launched in the past few years—and nearly all disguise the insects in familiar products.



Exo protein bar
Varieties: cacao nut, blueberry vanilla, apple cinnamon, peanut butter and jelly; \$2.99



Bitty cookies
Varieties: orange ginger, chocolate cardamom, chocolate chip; \$9.99



Crickers crackers
Varieties: rosemary garlic, classic sea salt; \$6



Hopper Crunch granola
Varieties: toasted coconut, cranberry & almond, cacao & cayenne; \$10



Critter Bitters
Varieties: pure cricket, vanilla, cacao, toasted almond; price N/A



Next Millennium Farms flour
Varieties: regular, organic gluten-free, organic; starting at \$15

with big-box stores. A cricket protein bar called Exo attracted \$54,911 on Kickstarter in 2013; the start-up has since sold several hundred thousand bars, raised an additional \$1.2 million, and may appear in JetBlue snack packs later this year. And Next Millennium Farms, which sells flour made from crickets it grows outside Toronto, raised \$1 million from private investors. “Some of the largest food production companies in the world are in talks with us—flavoring companies that sell to PepsiCo, Unilever, McDonald’s,” says co-founder Jarrod Goldin. “Food producers have had to pay attention to what is going on.”

Many in the new cricket industry also hope to ride a wave of other trends. Goldin, for

example, sells organic and gluten-free cricket flour and will soon add a paleo line of crickets that are fed a grain-free meal. But regardless of the sales pitch, packing crickets into the familiar shapes of cookies and snack bars doesn’t necessarily ease demand for more resource-intensive forms of protein (particularly with regard to products that may contain negligible amounts of cricket).

The best scenario for entomophagy advocates concerned about global food security is getting people to eat the insects as they are.

“When we started ordering crickets to our dorm, we realized America isn’t ready for that,” says Laura D’Asaro, who co-founded Six Foods shortly after graduating from

Harvard. “We see our chips and cookies as a first step. It’s useful just to have crickets on the ingredients list and have Americans eating them. But we want to slowly introduce other products, with the ultimate goal of going to a restaurant where you can get a chicken burger, veggie burger, or ento burger.”

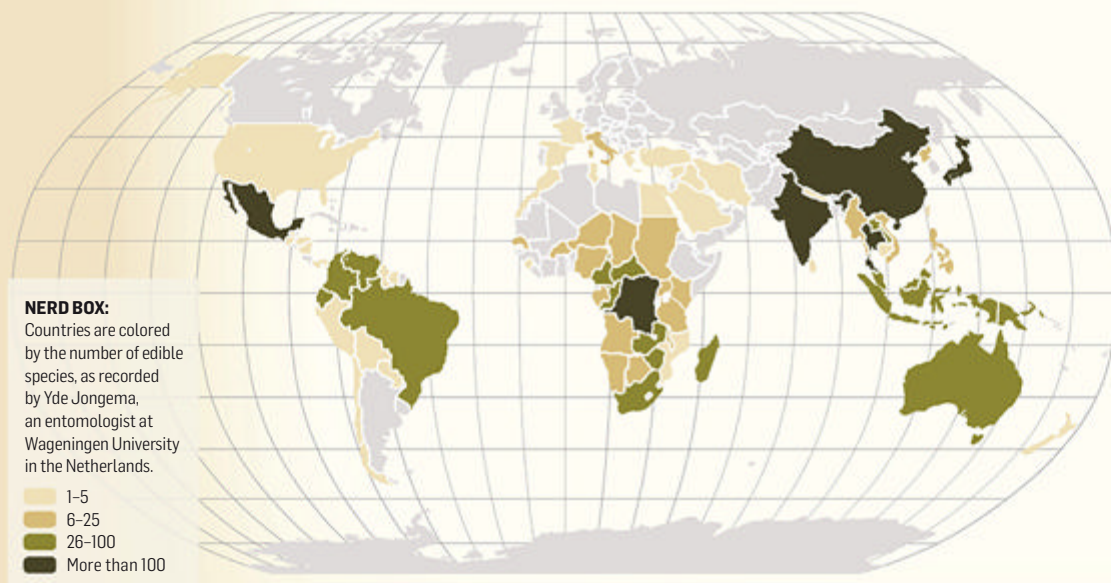
...

The culinary possibilities of ento food rest on a steady supply of the main ingredient, which is another reason crickets have taken off. North America already has an industrial cricket infrastructure; the insects have been grown

THE GLOBAL MENU

The Thai love fried locusts. South Africans munch on caterpillars. At least 2 billion people worldwide regularly eat insects, according to the Food and Agriculture Organization of the United Nations. Nutritionally, they

are hard to beat: Insects are high in protein, vitamins, minerals, fiber, and “good” fats. More than 2,000 species have reportedly been used as food—and with a million insect species and counting, more are sure to be found.



NUMBER OF EDIBLE INSECT SPECIES, BY TYPE



*NUTRITION INFORMATION IS PER 100 GRAMS OF DRY BUG



House Crickets

Asia, Americas

Acheta domestica is one of two species that farmers can raise economically.

Calories* 460

Protein 67 g



Palm Weevil

Africa, Asia, Americas

Larval palm weevils are by far the most popular beetle eaten in the tropics.

Calories 480

Protein 36 g



Ahuahutle

Americas

The eggs of back-swimming bugs have been eaten in Mexico for centuries.

Calories 330

Protein 57 g

BUG ILLUSTRATIONS BY BROWN BIRD DESIGN; SOURCES: “NUTRITIONAL COMPOSITION AND SAFETY ASPECTS OF EDIBLE INSECTS,” B.A. RUMPOLD AND O.K. SCHLÜTER, MOLECULAR NUTRITION & FOOD RESEARCH, MARCH 2013

for decades as fish bait and food for pet reptiles. To see how crickets are raised for people, last November, I took a trip to Big Cricket Farms in Youngstown, Ohio, the first food-grade cricket operation in the U.S.

The farm resides in a former vegetable co-op, a 5,000-square-foot warehouse tucked in the back of a parking lot. Kevin Bachhuber, Big Cricket's co-founder, had promised I would hear the chorus of breeders—mature crickets capable of reproducing—but when I stepped inside, I met only silence. A crisis of unknown origin had killed more than a million breeders weeks before my arrival. Luckily, I missed the direct aftermath: the deathly smell of 900 pounds of rotting cricket corpses. “It was like a little genocide,” Bachhuber said.

He and the company's cricket wrangler, Luana Correia, led me away from the empty breeder boxes to the nursery, split into two black tents. We pulled sanitary disposable booties over our shoes, unzipped a door, and stepped into an oppressive heat—the tents are kept at 90 degrees Fahrenheit and 90 percent humidity to nurture the young. It smelled like roasted nuts. Plastic boxes lined the walls, and Correia pulled one down to show me an egg carton inside. It teemed with uncountable baby crickets, nicknamed pinheads, the features on their fragile bodies nearly imperceptible. The tents hold three to four million in total. If they all grow to adulthood—unlikely, as pinheads are prone to accidental squashing—they will amount to 3,000 pounds of cricket meat, or 750 pounds of protein powder. By harvesting the adults every seven weeks, Big Cricket projects it will grow 60,000 pounds of crickets annually, and Next Millennium Farms, even more: up to 300,000 pounds a year.

The fledgling industry poses an interesting conundrum to government agencies. Like larger livestock, crickets are subject to federal and state regulations. Until the relevant agencies can sort out the finer points, both they and the start-ups they regulate have been collectively winging it. When Big Cricket Farms had to rebuild its stock after the mass death of its breeders, Bachhuber followed U.S. Department of Agriculture (USDA) organic chicken egg rules to decide whether eggs from a pet-grade cricket farm can be hatched for human consumption, for example. The FDA and the Ohio State Department of Health simply require a guar-

antee that food-grade crickets are farm-raised rather than wild-caught to avoid pesticides and other unintentional contaminants. And as of now, the USDA has no plans to inspect cricket farms and likely won't unless there is an obvious and widespread health problem or they begin producing amounts comparable

up,” Bachhuber told me, “is that your stress levels will never be higher.”

Big Cricket got its start through the Youngstown Business Incubator, and at the end of my visit to Ohio, Bachhuber and I headed to the former furniture store it occupies across town. A conference room had

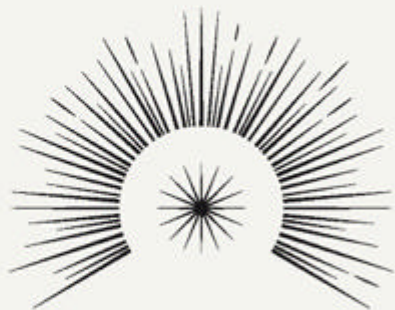
“THE ULTIMATE GOAL IS GOING TO A RESTAURANT WHERE YOU CAN GET A CHICKEN BURGER, VEGGIE BURGER, OR **ENTO** BURGER.”

to beef and other meat, says Sonny Ramaswamy, director of the National Institute of Food and Agriculture. That's not likely anytime soon: Americans alone eat about 26 billion pounds of beef a year.

Although crickets are unlikely to transmit illnesses like mad cow disease or swine flu, they do get sick, and that is perhaps the trickiest part of the business. Big Cricket Farms chose the European house cricket, *Acheta domesticus*, for its taste and nutritional profile. But the species is prone to cricket paralysis virus, which can whip through a farm and leave 95 percent of the insects dead. It's also the only farmed cricket subject to a less contagious picornavirus, which I later learned may have caused the die-off at Big Cricket. The company subsequently switched to a hardier stock: the tropical house cricket, *Grylodes sigillatus*. It also began researching a receiving room that would disinfect new shipments of eggs or crickets with virus-killing ultraviolet light. “The nice thing about being in the first year of operations of a start-

been set up for a small reception, and a long table held typical party fare: platters of cheese and hard sausage, veggies with dip, chips, and crackers. At the end of the row sat one bowl of homemade cricket pesto and another with whole crickets sautéed in garlic. The pesto looked like any other, and I spooned some on my plate. But the crickets—there was no abstraction here. These had eyes, antennae, and legs. *If this is the future, might as well see what I'm in for*, I thought.

I can't say the crickets went down smoothly. I had to drown them in pesto and shovel them in with a cracker. It was an eating experience reminiscent of childhood, when my parents made me take just three more bites of an unfamiliar food before I could leave the table. As then, I did so warily, willing my tongue and teeth not to explore. I'm no picky eater these days, but if consuming whole insects is the eventual goal, I think it will take a while to convince the American palate. But that cricket pesto? Washed down with a cricket bitters cocktail? That, I'd have weekly. 🍷



Nothing but the Truth

SCIENCE'S GREATEST
WEAKNESS IS ALSO ITS GREATEST
STRENGTH

BY **Alan Lightman**



Alan Lightman is a physicist, novelist, essayist, and educator at the Massachusetts Institute of Technology and a finalist for the National Book Award.

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Forty years ago, the legendary physicist Richard Feynman gave the commencement address at my graduation from the California Institute of Technology. It was a boiling day in June, and we graduates—all budding biologists and chemists and physicists—sprawled in folding chairs on the lawn, sweltering in our black gowns. Feynman told us that before we went public with new scientific results, we should consider every conceivable way we might be wrong. It was a tall order.

A recent case in point was the discovery, in March 2014, of evidence that purportedly confirmed the theory of inflation. According to the theory, proposed by physicists Alan Guth, Andrei Linde, and others in the early 1980s, the universe briefly inflated at an exponential rate when it was about one trillionth of a trillionth of a trillionth of a second old. It then slowed to adopt the more leisurely expansion predicted by the standard big-bang model. The theory of inflation naturally explained a number of observations not easily accounted for by the big-bang model, and it has been almost universally accepted by practicing cosmologists ever since.

But science places more value in predicting new phenomena than it does in explaining results already known. Years ago, the theory of inflation predicted a particular twisting pattern in the vibrations of the radio waves that pervade outer space, the so-called cosmic background radiation. Scientists studying three years' worth of data from the BICEP2 observatory at the South Pole found such a telltale pattern last spring. The team involved more than 50 scientists and was led by John Kovac of the Harvard Smithsonian Center for Astrophysics. The story immediately

went viral. In a press release titled “First Direct Evidence of Cosmic Inflation,” Kovac said, “Detecting this signal is one of the most important goals in cosmology today.” A YouTube video posted by Stanford University shows one of the team members excitedly telling Linde that they had found “the smoking gun of inflation,” after which they celebrate the success with a bottle of champagne, no

scientific community, with researchers constantly testing and criticizing one another’s work. Individual scientists are driven by the same passions and biases and emotional attachments as nonscientists. Most try their best to be objective, but, as Francis Bacon, one of the fathers of the scientific method, said four centuries ago, “The human understanding is no dry light but receives infusions from



PASSION IS A DOUBLE-EDGED SWORD,
ONE THAT CAN BESTOW BOTH FORTUNE AND
MISFORTUNE UPON THOSE WHO WIELD IT.

doubt anticipating Nobel Prizes.

Then in January, another team of astronomers, using data from the European Union’s Planck satellite, announced that the twisting pattern was not actually caused by exotic processes at the birth of the universe. Instead, it was produced by galactic dust. It’s not that the Kovac group did sloppy work. Rather, the scientists had failed to follow Feynman’s advice. In their ardor to confirm what would have been one of the greatest scientific discoveries of the century, they had not sufficiently considered the possible competing effects of galactic dust—effects that other scientists had worried about at the time.

The history of science brims with similar cases, where eager scientists leaped to press too soon. One need only remember the 1970s-era anticancer drug Laetrile, which supposedly destroyed tumors; the reported discovery in 1975 of “magnetic monopoles” (magnets with either a south pole or a north pole but not both); and the reported achievement of cold fusion in 1989. Other scientists later disproved every one of these claims.

In fact, professional historians and philosophers of science know a dirty secret. The much-vaunted “scientific method” and its objective pursuit of truth often cannot be found in the work habits of individual scientists. It’s manifest only in the combined efforts of the

the will and affections.”

This year, in particular, it would be wise to keep Bacon’s warning in mind. In March, the world’s most powerful particle accelerator, the Large Hadron Collider (LHC), came back online after a two-year hiatus and an upgrade that doubled its energy. In 2012, the LHC helped scientists find the long-sought Higgs boson. This year, it could do the same for dark matter, a mysterious and still unobserved subatomic particle believed to make up about 27 percent of the universe. Elsewhere, physicists are mounting at least four major experiments to confirm the existence of dark energy, a similarly unobserved substance theorized to create a kind of negative gravity that causes space to expand at an accelerating rate. Astronomers are getting their first good looks at the comet 67P/Churyumov-Gerasimenko and the dwarf planets Pluto and Ceres, all of which could yield clues about the formation of our solar system. And the hundreds of biologists and neuroscientists involved in the Human Brain Project in the EU and the BRAIN Initiative in the U.S. will be investigating the riddles of brain function more deeply than ever before. Evidently, we may be in for another year of irrational exuberance.

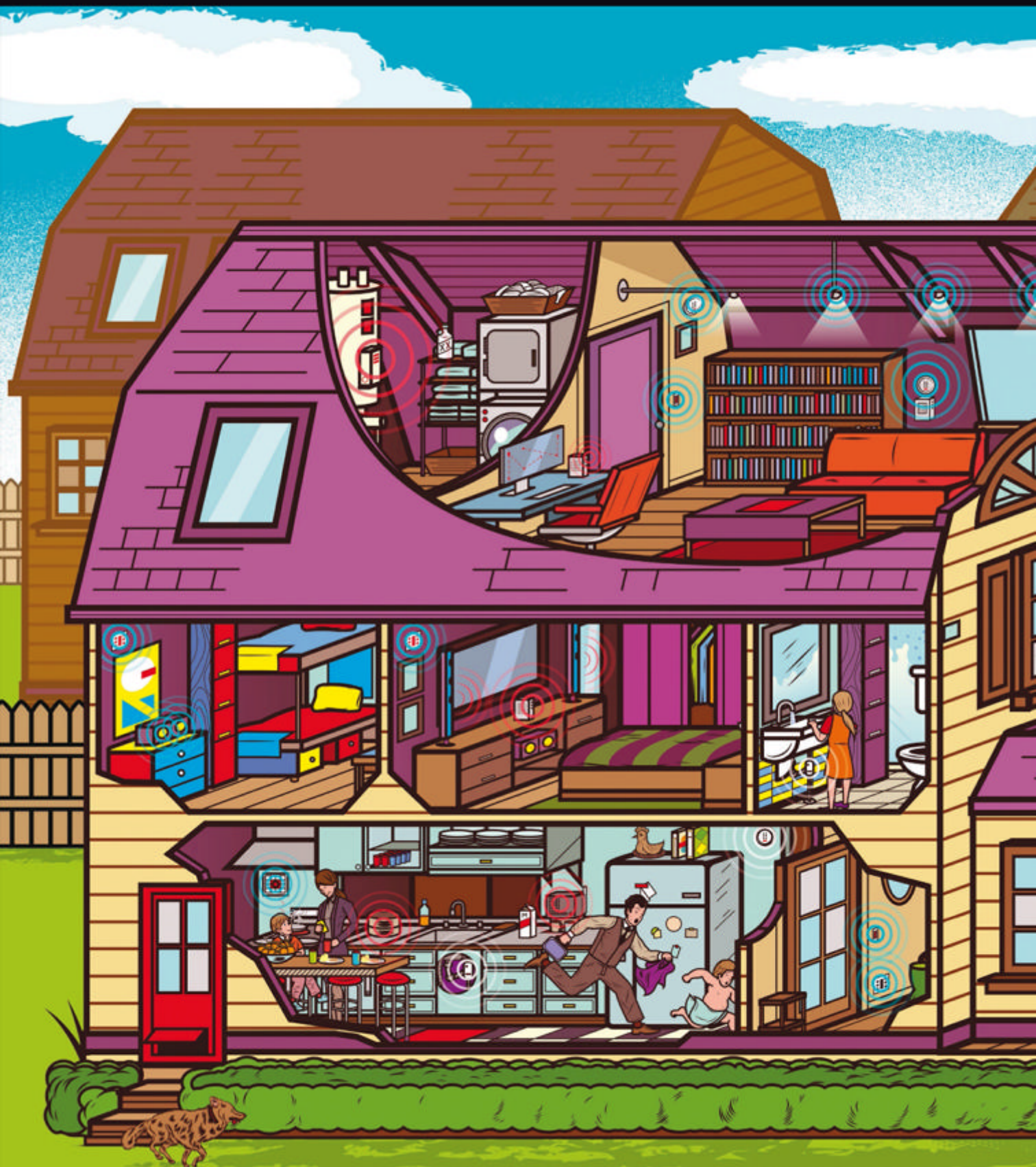
And yet that may not be so bad. Exuberance carries its share of risks, certainly, but I would argue that it’s also

essential to the enterprise of science. Without personal investment and passion, most scientists would not struggle with their research projects for months and years as they do. They would not stay up all night in their labs as they do. They would not endure the tedium and strain and constant possibility of failure or dead-end results. I remember well my days and nights working in astrophysics, thinking about my current research problem nearly every minute of the day, sometimes eating meals of peanut butter at my desk so as not to interrupt my feverish calculations. All my energy, my thoughts, even my personal identity and self-worth hung on those calculations.

Science would not proceed without such devotion. And there is the irony. Passion is a double-edged sword, one that can bestow both fortune and misfortune upon those who wield it. Passion is the stuff that drives us on, but it can also cloud our vision. The late physicist Joseph Weber argued for decades that he had observed gravitational waves with acoustic cylinders of his own making, and he adamantly defended those claims against overwhelming evidence to the contrary. Ultimately, that work was discredited, yet the concepts and equipment he developed serve as the basis for all gravitational wave detectors in use today.

We often make sharp distinctions between the sciences and the arts and humanities. Science aims at the external world of atoms and molecules, while the arts and humanities concern the internal world of emotions and sensibilities. Certainly, these distinctions are valuable as guiding principles, but in individual people, whether scientists or not, such neat separations do not occur. Nor in my view would they be desirable.

At its core, science is a human endeavor. Its strengths and flaws mirror our own. We should, of course, aspire to Feynman’s advice, to accept nothing but the truth. But we also need to accept human beings in their totality, both as scientists and humanists, as objective and subjective, as dispassionate and passionate, as travelers in this strange cosmos trying to make sense of our world and ourselves. ✎

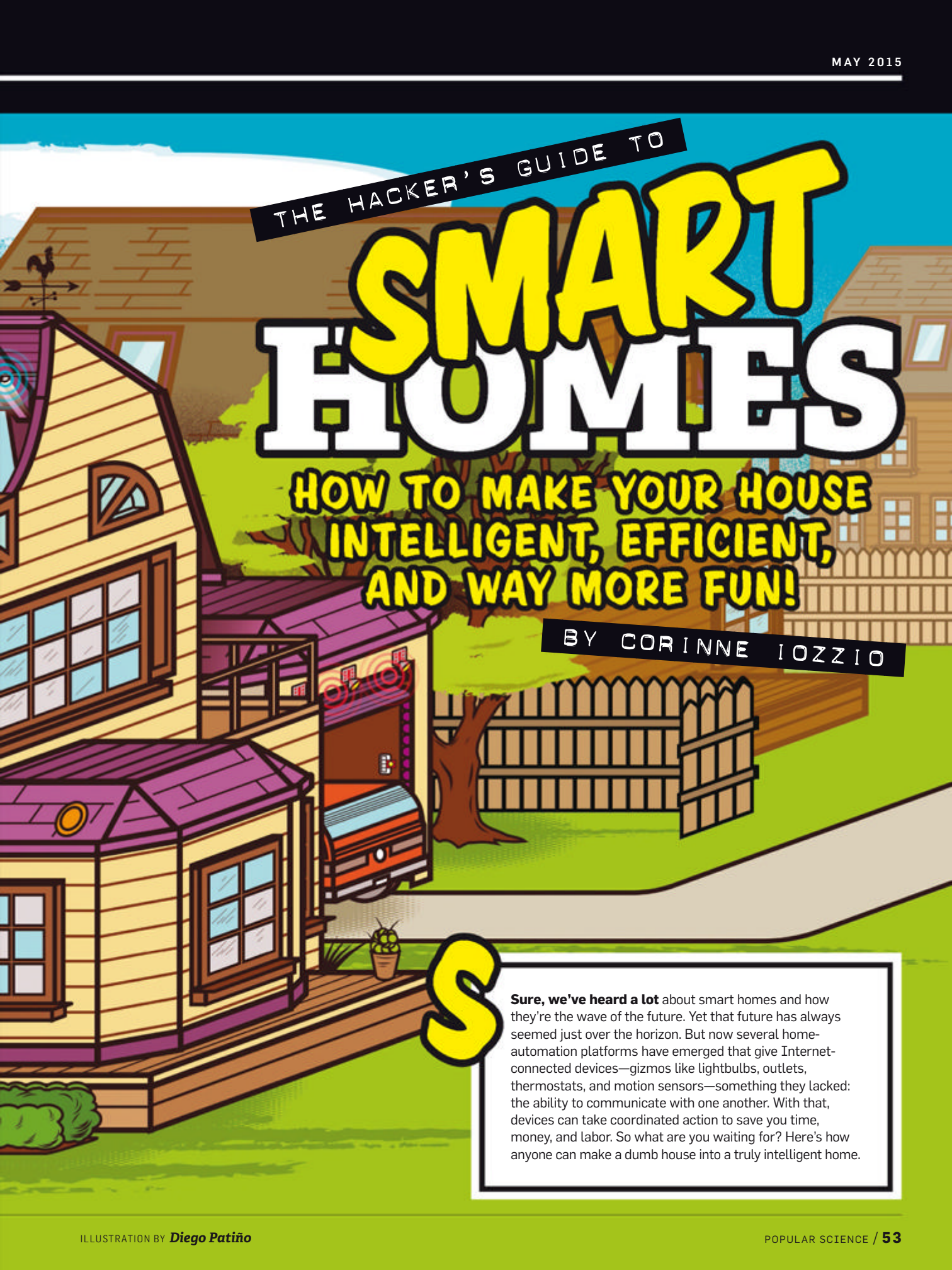


THE HACKER'S GUIDE TO

SMART HOMES

HOW TO MAKE YOUR HOUSE INTELLIGENT, EFFICIENT, AND WAY MORE FUN!

BY CORINNE IOZZIO

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Sure, we've heard a lot about smart homes and how they're the wave of the future. Yet that future has always seemed just over the horizon. But now several home-automation platforms have emerged that give Internet-connected devices—gizmos like lightbulbs, outlets, thermostats, and motion sensors—something they lacked: the ability to communicate with one another. With that, devices can take coordinated action to save you time, money, and labor. So what are you waiting for? Here's how anyone can make a dumb house into a truly intelligent home.

STEP
1

PICK YOUR PLATFORM

Different products can cause chaos when they don't communicate. So choose a platform that uses a networking hub or an app (or both) to marry disparate devices and give your house a centralized brain from the get go.



For the Keyboard Banger *Belkin WeMo*

Most WeMo devices can connect to an app right out of the box, no tinkering required. But simplicity brings limitations—there are only 14 products to choose from. **(Products \$30–199)**



For the Weekend Webmaster *Wink*

Wink uses a hub and a smartphone app to connect unrelated brands and devices, bringing more gadgets—think locks and self-closing blinds—into the fold. **(Hub \$50)**



For the GeniusBar Nerd *SmartThings*

With 150 third-party products, this hub-and-app system accommodates plenty of gadgets. Users can also design their own interactions. The trade-off is a trickier setup. **(Hub \$99)**

STEP
2

SWAP YOUR FIXTURES

The core of a smart home is the ability to monitor and remotely control power, lighting, and security. That means replacing—or upgrading—everyday household fixtures, such as outlets and bulbs, and installing environmental sensors that will let you monitor what happens around the house.



Lightbulb *Cree Connected LED*

Cree eliminated the heat sink typical of most LEDs, cooling its bulbs through a series of vents. Its design gives the bulb an omnidirectional shine—just like its incandescent forebearers. **\$15**



Electrical Socket *Quirky+GE Outlink*

Disguised as an everyday pair of outlets, the socket has one smart and one dumb receptacle. That means you can remotely kill power to the coffeepot without tripping the fridge. **\$50**



Water Sensor *Belkin WeMo Water*

This sensor monitors an entire house's water usage from a single point. When clamped onto a pipe, a pressure sensor detects subtle shifts—from an open faucet to a costly leak. **Price not set**



Door Lock *August Smart Lock*

The clever kit fits over an existing deadbolt, so there's no need to replace the entire lockset. Once installed, you can issue guests digital keys or set the lock to open as you approach. **\$250**



Smoke & CO, Alarm *First Alert ZCOMBO*

The ZCOMBO alarm not only sends emergency alerts, it triggers other devices in your network. For example, during a fire it can trip the lights so you can find your way out. **\$50**



Doors & Windows *SmartSense Multi Sensor*

A pair of mounted magnets can tell whether doors, windows, or even mailboxes are open. The sensor can also cue common tasks, like killing the AC if you open a window. **\$54**



Environment *Quirky+GE Spotter UNIQ*

The Spotter senses up to six environmental cues: motion, vibration, sound, temperature, humidity, and light. It can turn on hall lights as you approach or alert you when the dryer stops. **From \$70**



Light Switch *Belkin WeMo Light Switch*

Until there's a smart-bulb equivalent for every light, connected switches imbue otherwise dumb fixtures with brains. The app also lets you sync lights with sunrise and sunset. **\$50**



Security Camera *Dropcam Pro*

With a 130-degree field of view, 8x zoom, and infrared night vision, the Dropcam Pro's unblinking eye allows you to peek inside your home without racing to the scene. **\$199**

COMING SOON!

VOICE CONTROL

Clever DIYers have rigged smart homes to respond to commands from Siri and other voice assistants. Apple made the connection official. Starting this spring, manufacturers can now use Apple's HomeKit system to make their products react to commands dictated to an iPhone. For instance, "Siri, I'm heading home" could turn on lights, adjust the temperature, and start the stereo.

STEP
3

CONTROL YOUR CLIMATE

All smart thermostats share a common goal: save money while staying comfortable. An Internet connection allows them to adjust the indoor temperature based on outdoor conditions—some even factor in humidity. But the best way for a home to adapt to its residents is still up for debate. Your schedule may dictate which method is best for you.

If you have a regular routine ...

The Nest Learning Thermostat (\$249) uses algorithms to learn from your patterns. The device monitors when you change the temperature and builds a schedule. Eventually, Nest takes over, so when you wake up or arrive home, the house will already be at your ideal climate. Recent studies have found that using Nest can save up to \$145 annually.

If you come and go a lot ...

The Honeywell Lyric Thermostat (\$249) shifts its energy-saving mode based on whether there are people in the house. Family members give Lyric access to their whereabouts via a smartphone app. When they pass a geofence, a preset distance that can range from 500 feet to seven miles, the system toggles on or off. This could cut annual costs by up to \$220.

STEP
4

AUTOMATE

After setup, you can teach the smart home to think for itself, freeing you from using an app every time you want to change the temperature or turn on the lights. That means creating automated actions; because each platform can talk to all the gadgets you have online, they can suggest scenarios and guide you through the setup process. Here are a few examples of what your smart home can do:

Schedule Method

Create standard operating procedures signaled by specific times of day.

Sunset. Action: Close blinds and increase interior brightness by 50 percent.

9 p.m. Action: Cut power to playroom TV.

Tuesdays 1 p.m. Action: Allow cleaning crew inside.

Stimuli Method

Triggers take input from a sensor (or sensors) and translate it into an action to be carried out by another device.

Movement in the bedroom after 6 a.m.

Action: Power on coffeepot.

Opened living-room window.

Action: Turn off AC and turn on floor fan.

Homeowner leaves house.

Action: Lock the door and lower the thermostat.

DUMB SMART THINGS...

A few so-called smart appliances are conspicuously absent here because we've set the bar high: Devices must not only connect to the Internet but also to one another, creating a network of shared data and automated tasks. Two categories that are not ready:

TVs: Their smarts consist only of an Internet connection and the ability to stream media from Netflix, Pandora, and the like.

Large appliances: Ovens, washers, dryers, and refrigerators will be the next wave of smart items, but today, they're still learning the ropes. Prototypes do show promise: Whirlpool, for example, is developing a dryer that will shift into a slower cycle if you're not home to empty it.

...JUST PLAIN DUMB

Adding intelligence doesn't always make an object better, says Matt Rogers of Nest Labs. So we asked him: What's best left alone?

Mirrors: Too niche

"What's the good of having your mirror filter out gray hairs or count your brush strokes? Unless you're the Wicked Queen, this is not a problem."

Toasters: Unsafe

"When you're 3 years old, mothers are supposed to teach you to turn all that stuff off when you leave the house."

Sofas: Missing the point

"Imagine the couch telling you that you've been sitting on it too long and that you've put on a few."

STEP
5

ADD SOME KICKS

Finally, not all smart-home devices are needed—some get by because they add frills (or fun) to our lives.



Crock-Pot Smart Slow Cooker

A six-hour recipe and an eight-hour workday don't mesh; thankfully, you can start, stop, or turn down this cooker from afar. **\$130**



Jawbone UP24

Not only can this activity tracker alert your house when you come and go, but it also knows when you're asleep. Nod off and it'll turn off the lights. **\$130**



Sonos PLAY:1

Sonos speakers respond to triggers from in-home sensors. If you want your stereo to play "Welcome to the Jungle" whenever you walk in the door, Sonos will. **\$199**

IN THE WORKS!

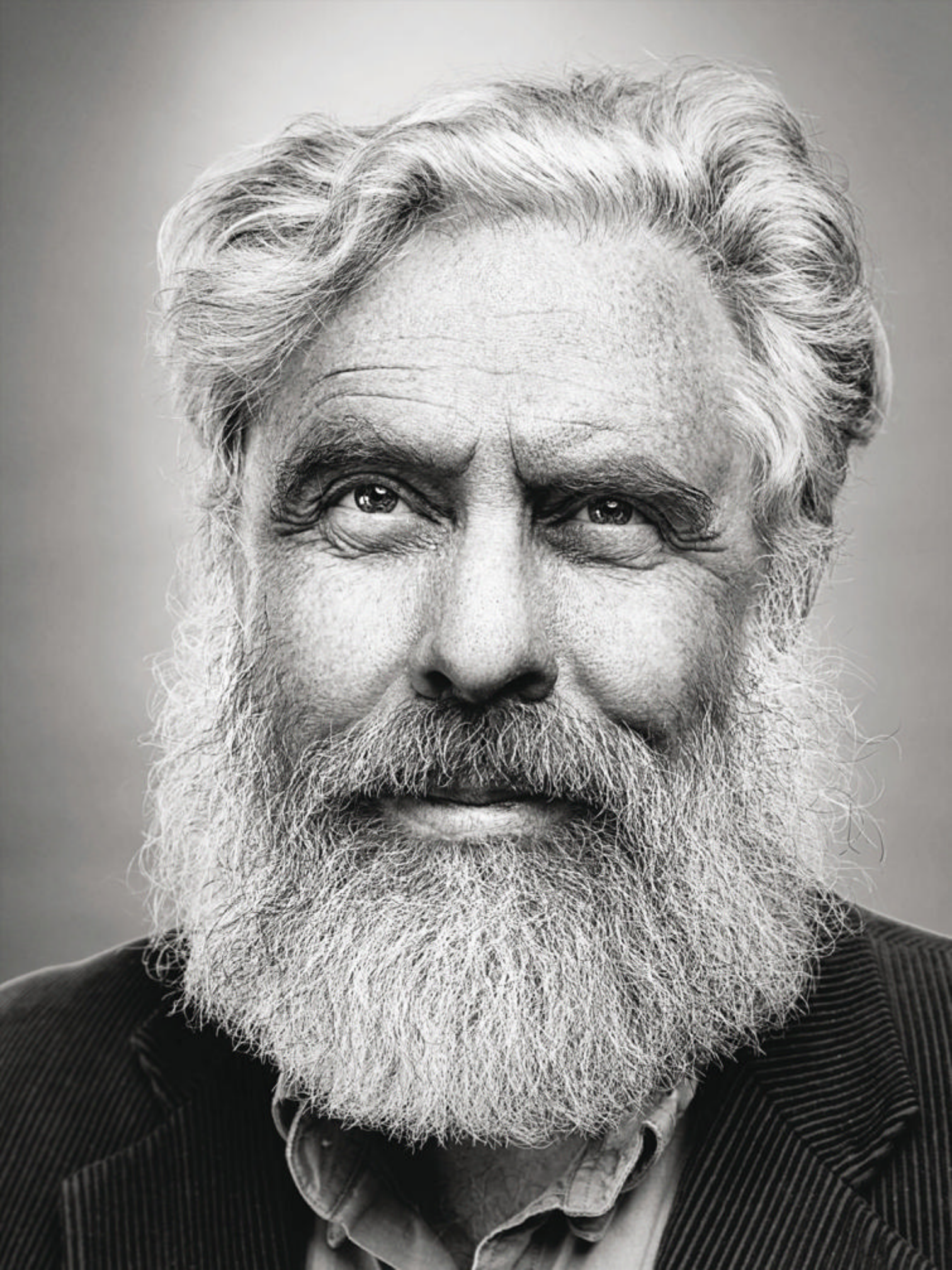
ARTIFICIAL INTELLIGENCE

Machine-learning algorithms in products like the Nest thermostat are only the beginning of a self-automating home. Soon, apps might recommend tasks based on patterns—"I see you turn on the lights at the same time every day, shall I schedule this task?" But the ultimate goal is autonomous artificial intelligence, where you'd buy a product and your home would figure out the rest. For now, SmartThings founder Alex Hawkinson says, "We're probably years from saying 'I'm gonna go live my life and let the tech figure itself out.'"

THE CHURCH OF CHURCH

BY
JENEEN
INTERLANDI

CAN A SINGLE SCIENTIST
TRANSFORM THE FIELD OF BIOLOGY—
AND OUR LIVES?





A few years ago, George Church was peer-reviewing a paper for the journal *Science* when he got an idea. The paper's authors had encoded their names and a string of famous quotes into a bacterial genome to demonstrate the power and possibility of synthetic biology, the design and manufacture of DNA in a lab. Their encoding method was good. But Church, a genetics professor at Harvard Medical School, thought he could do better.

Sitting at his desk, in the space of a few minutes he wrote a computer program that translated his review from Roman letters into binary code and then into genetic code. He submitted the review to the journal's editor, who couldn't read it. The document contained only As, Ts, Cs, and Gs, shorthand for the nucleotides in DNA. The editor passed it along to the study's authors. "At first, they had no idea what it said," Church says, chuckling.

That should have been the end of it. The paper was published, and the stunt passed quickly into the stock of Church lore, in league with the time he lived for a year on nutrient broth from a lab vendor or the time he wore homemade blinders around the lab to make a statement about tunnel vision.

But Church wasn't done. He wanted to see how far he could take his computer program, so he began looking for something else to code, something larger than a single review. He settled on his own book, *Regenesis*, which was about to be published. He spent a few days adapting the program he'd written and converted all 350 pages of text and photos into a string of As, Ts,

Gs, and Cs. In the lab, he synthesized a strand of DNA to match the code, replicated it many times over, and dabbed a drop of the synthetic DNA onto a scrap of paper. The dot contained 70 billion copies of the book. It

**CHURCH IS HELPING TO
FORGE A NEW KIND
OF BIOLOGY, ONE LESS GEARED
TOWARD STUDYING DNA
THAN HARNESSING IT FOR
OUR OWN AIMS.**

was no bigger than a period.

A few months later, Church took his experiment with him on *The Colbert Report*, pulling out the paper scrap—about the size and shape of a fortune cookie slip—for the world to see. Before he knew it, representatives of several companies tasked with archiving films and recordings were knocking on his office door.

"They said, 'We want to do data storage,'" Church tells me. "I said, 'You guys realize this is super academic, right? There's no company or anything.' And they said 'Yeah sure, but data storage is a big problem.'"

With that, his parlor trick sprouted into a business. Members of Church's lab are now scaling up the process in order to encode just about any form of media into DNA. If they succeed, they will have not only revolutionized data storage but ushered in what is perhaps biology's most exciting era: the

era when our capacity to manipulate the basic code of life dwarfs the capacity of even our most advanced computers.

Church tells the story pretty calmly, considering. We're sitting in his office, a generous space tucked into the side pocket of a large lab, with windows that look down on Boston's Longwood Avenue. He's leaning back in his too-small office chair, stretching his legs out in front of him (he's six-foot-five) and occasionally tugging at his Darwin-esque beard. He has blue eyes, a kind face, and an even voice, none of which betray the excitement or manic brilliance that one assumes must fuel such breakthroughs. If anything, he seems entertained. This is an amusing anecdote. The rest is an aside.

Church has already transformed biology once before. The DNA-sequencing technology he first devised in graduate school helped reduce the cost of whole-genome sequencing from billions of dollars to thousands. Scientists are now using it to investigate intractable diseases, such as cancer and schizophrenia, and doctors are beginning to use it to identify genetic mutations that cause rare—and, until now, undiagnosable—illnesses.

Amid the bays and bench tops that constitute Church's laboratory, a litany of other revolutions are taking shape: His team of researchers is coaxing the woolly mammoth back from extinction by melding its genome to an elephant's. They're devising ways to inoculate mosquitoes (and, by extension, us) against malaria. And they're designing tools to help physicists hunt down dark

matter and to help neuroscientists map the human brain. Church has launched 15 bioengineering start-ups in the past decade and advises a number of others. More so than any other scientist in his field, he is helping to forge a new kind of biology, one less geared toward studying DNA than harnessing it for our own aims.

In the book that he encoded in DNA (which, incidentally, is also available printed and bound), he and his co-author, Ed Regis, envisioned the future this new biology could bring, one in which bacteria fuels cars and commercial jets and humans are immune to cancer. It may sound like science fiction, or at least like a litany of overhyped pipe dreams that science so often sells. But George Church's pipe dreams have an uncanny record of becoming reality.



For all his eccentricities, Church is an easy person to talk with. And yet such is his reputation for brilliance that people seem always to be apologizing to him for their own intellectual shortcomings. "I'm sorry if this sounds stupid," people say. I caught a reporter doing it, and a CEO. Then, I did it too.

In fact, on my first visit to his office, I manage to completely embarrass myself. It's early afternoon, and he's invited me

The Church of Church



At Harvard, Church attacks many of the world's hardest problems with genome editing.

to sit in on a telephone interview with a radio reporter, before I tag along to some meetings. A handful of 3-D-printed molecules are scattered across the big round table in the center of his office. He has been fidgeting with one—absentmindedly pulling it apart, between his thumb and forefingers before letting it snap back together—while he leans back in his chair and talks at the speakerphone. I pick up another molecule, one that looks identical to his but is not. Instead of snapping back together when I pull at it, it explodes.

Twelve plastic pentagons and one large white die go flying through the air. They skittle loudly across the table and roll onto the floor. Some of them land under Church's desk. I am mortified. I scramble to gather all the pieces and reassemble them as quietly as possible, while he calmly continues to answer questions about genomic medicine.

When the phone call ends, I make sheepish apologies. "I thought by the way yours was snapping back together ..." I say, trailing off into the ether.

Unfazed, he takes the two molecules, holds them side by side, and launches into a geometry lesson. They are both dodecadodecahedrons, he explains—objects with 12 sides. He has rigged his with some putty to prevent the pieces from disassembling; mine has not been so rigged. It is also wrapped around a 20-sided die, or an icosahedron. "I found this die on the street," he says. "I like it because it looks like the nuclear material of a virus." He goes on to explain the significance of these shapes: Icosahedrons are among the most symmetrical structures in the natural world, he says. They also form the basis of viral symmetry. I pretend to understand, but my takeaway is simpler than he probably intends: George Church is the kind of guy who finds a 20-sided die and immediately thinks about the structure of viruses.

He has been tinkering like this—testing the ways in which the world around him does and does not fit together—for most of his life. When he was 10 years old, he began replicating the work of a botanist named Luther Burbank by grafting the branches of one fruit tree onto another in his backyard. As a teenager at Andover, a private school, he taught himself BASIC computer programming and then taught the school's computer linear algebra. As an undergraduate at

Duke University, he raced through the curriculum and simultaneously completed two bachelor's degrees (in zoology and chemistry) in two years. As a graduate student there, he helped solve the structure of transfer RNA, which translates the nucleic acids of DNA into the amino acids of proteins. He spent so much time in the lab that Duke expelled him from its Ph.D. program for missing too many classes. Fortunately, Harvard took him in.

"It was pretty clear he was a different sort of bird right from the beginning," says Gary Ruvkun, a Harvard geneticist and good friend of Church's (the two attended graduate school together). "I still remember I would work late, and when I'd be leaving the lab at, like, 2 a.m., he'd be buzzing in on his bike, ready to start the day."

It was at Harvard that Church met his future wife, a fellow graduate student named Ting Wu. He followed her across the country and back before the couple settled in Boston to grow their labs (both at Harvard) and their family (they have one daughter, now in her 20s). His wife, he says, is a much better geneticist than he. In fact, Church is fairly adamant that he's not a scientist at all but an engineer who occasionally does some science.

Like an engineer, he tends to see the universe not as a disparate set of mysteries but as a machine with a vast array of buttons and levers, each begging to be pushed and pulled. "His approach to science is modeled after the home-brew computer clubs, where

the computer revolution was started in basements and garages," Ruvkun says. "He told me once that he's more proud of his National Academy of Engineering membership than of his National Academy of Sciences one. Nobody else I know thinks that way."

Here's how it goes in most academic laboratories: A scientist develops proficiency in a handful of techniques and uses those techniques to study a handful of closely related questions. That lab attracts students and junior researchers with narrowly aligned interests and experiences. The entire system tends toward specialization, so that, by and large, molecular biologists interested in immunology and experienced with mice go to one kind of lab and neuroscientists interested in the visual system and experienced with flies go to another. Expertise is cultivated and refined and, in some cases, hoarded like wartime food rations.

Church's lab is the opposite. Rather than seeking homogeneity, he recruits as diverse a group as possible. Physicists and neuroscientists work alongside geneticists, engineers, and entrepreneurs. "The image for me is of poking deep holes all over the place, in the fabric of science and engineering," he says. "As we probe each of those points, we get cross talk."

The result is that his lab manages to be both one of Harvard's top producers and a well-known receiving center for science's misfit toys. There's an artist encoding Wikipedia entries into apple genomes (to create a literal tree of knowledge) and an insurance industry refugee who fled his office job over a decade ago, worked several months for free while teaching himself biochemistry, and now serves as "co-head" of the lab. For a time, there was also a passenger-pigeon obsessive who had no advanced degree but had heard about Church's mammoth de-extinction project and cold-called asking to participate; he has since gone on to lead the pigeon resurrection initiative out of a lab in California.

"We always joke that the only thing

The Church of Church

you need to do to join George's lab is show up," says Uri Laserson, a former student of Church's and the co-founder of Good Start Genetics, a company that offers genetic screening for inherited diseases. "There is zero organization. His style is just to let things happen." It's a scrappy kind of place, Laserson says—a little bit sink-or-swim—but not in a bad way. "Mostly, you have the constant sense that exciting things are happening or are about to happen and if you miss out on it, you have only yourself to blame."

The projects that emerge from this controlled chaos seem to fall along a continuum. At one end, the lab applies biology to very specific nonbiological problems. Data storage is an example, but lately, members of Church's lab have been using DNA to help physicists track dark matter, a mysterious substance that makes up some 27 percent of the known universe. At the other end of the continuum, Church's team employs the tools of other sciences to solve the problems of biology. For example, the newly developed technique FISSEQ (fluorescent in situ sequencing) draws on a few different subsets of physics to help geneticists visualize gene expression in living cells. Before FISSEQ, scientists could measure just three or four genes at a time; now, they can measure thousands at once.

But it's the projects in the middle of the continuum—biology-based solutions for biology-based problems—that tend to garner the most attention. Many of these involve CRISPR, a genome-editing tool derived from bacteria that uses an enzyme to excise specific nucleotide sequences and swap them with others. With it, scientists can alter multiple genes at once, without having to do the arduous work of extracting, isolating, and cloning the original genetic material and cross-breeding the resulting transgenic animals. A few other tools offer a similar shortcut, but CRISPR is much quicker. "It's the fastest thing I've seen yet," Church says. "It's like you throw a piston into a car and it finds its way

to the right place and swaps out with one of the other pistons—while the motor's running."

In January 2013, Church was one of the first to show that CRISPR could splice DNA in human cells. Since then, scientists have used it to correct a number of genetic problems, including certain forms of liver disease (in mice) and antibiotic resistance.

Church says CRISPR can address ecosystem-level issues as well. By circumventing the rules of sexual selection with live genome editing, CRISPR greatly increases the odds that a given gene will be passed from parent to offspring. The result is what scientists

that has borrowed genes from the woolly mammoth so that it can thrive in colder environments. It could be possible to resurrect other species using the same approach, Church says. In fact, the possibilities are as limitless as our imaginations.

Whether that's a promise or a peril depends on whose imagination we're talking about.

Before Church broke out the 70 billion copies of his book on *The Colbert Report*, the comedian asked him a question he gets a lot. "How do you think your work," Colbert asked, "will eventually destroy all mankind?" The audience laughed riotously. "Do you think it's going to be like a killer virus," he asked, pausing to lean in and tap his fingers on the table. "Or more like a giant, mutant, killer squid man, who arises from the Pacific, between Easter Island and Chile, and feasts on our flesh?" Although it was a joke, the bit underscored a paradox that Church often faces in response to his work. On one side, there are skeptics who don't believe the possibilities Church is peddling. On the other side, there are terrified believers who worry that it may be all too possible. Often, he alone stands in the middle.

Church tends to view this paradox through the same lens that he views most everything: as an engineering challenge. Take gene drives, for an example. Terrified believers worry about what could happen if a given gene drive has unintended effects. Say scientists introduce a gene that makes mosquitoes resistant to malaria, but that in turn causes an unexpected crash in the mosquito population that throws the ecosystem out of whack. Church's response to such a disaster would be simply to deploy a reverse drive to try to undo the damage. Skeptics have a different set of concerns, namely that natural selection would just weed out the new gene over time, making gene drives unworthy of the effort and risk. To this, Church just says we could deploy the same drive periodically, making slight tweaks here and there.

To play either of these scenarios forward is to see the world through Church's eyes: a place where DNA is the ultimate computer code and we are all computer programmers.

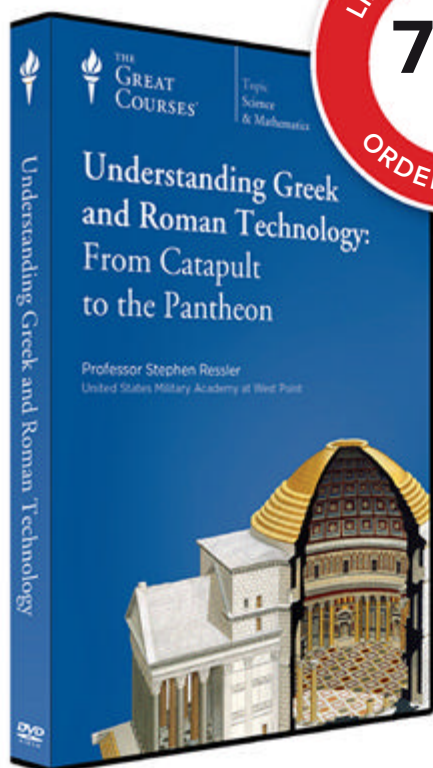
Of course, not all concerns are technical. Animal rights activists worry about a surge in animal experimentation now that CRISPR has made it easier than ever to create, for example, genetically modified monkeys. And corporate watchdogs have their own concerns about placing control of the human genome in the hands of private for-profit companies. It bears stating that Church works with a number of corporate sponsors, including Chevron, Procter & Gamble, and Merck.

Church makes no apologies for his entrepreneurship. He nearly always opens his lectures with a slide that displays all

**"THE WORLD WIDE WEB WENT
FROM ZERO TO MILLIONS OF WEB
PAGES IN A FEW YEARS.
MANY REVOLUTIONS LOOK
IRRELEVANT JUST BEFORE THEY
CHANGE EVERYTHING."**

call a gene drive: That is, a gene is driven quickly through an entire wild population. Imagine that you insert a gene for malaria-resistance into a single mosquito and release that mosquito into the wild. You may eventually wipe out the disease altogether. Or imagine inserting a gene that renders an invasive species sterile. You could potentially rid an ecosystem of that species within a few generations.

CRISPR is also a key component of what may be the most high-profile of Church's projects: de-extinction. When Stewart Brand, editor of the famed *Whole Earth Catalog*, hatched a plan to revive extinct species such as the woolly mammoth and the passenger pigeon, he turned to Church for the technology. Church devised an automated genome-engineering process (called the "evolution machine" by some) that enables researchers to meld together genomes from different species. His lab is now at work on a "cold-resistant elephant"—an elephant



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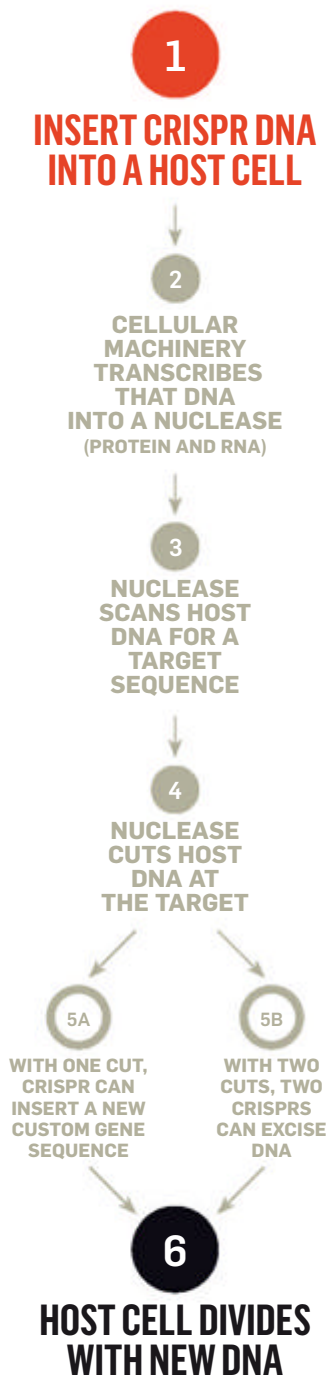
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A tool called CRISPR could herald the start of a revolution in genetic engineering. But to understand why takes some doing. Bear with us. Modifying genes used to require a painstaking process: Scientists would kill a cell, extract the DNA, manipulate it, and then reinsert it. Several tools now provide a shortcut, and CRISPR is the most efficient. Its protein complex swaps a targeted genetic sequence with another, allowing scientists to engineer DNA in living cells with unprecedented speed. Using CRISPR, scientists could modify genes to prevent disease, slow aging, bring back extinct species, even develop new fuels. The possibilities are almost limitless. **JUNNIE KWON**



the logos of the companies he's affiliated with. He agrees that there are risks involved in the work he does, but he does not think that vilifying corporations is the answer. "Industry is an essential part of what we do," he says. "You can't just hoard your ideas inside

the ivory tower. You have to get them out into the world."

Still, he takes safety concerns seriously. Last summer, Church and a few colleagues published two papers and one blog post on the same day, introducing the concept of

gene drives and calling for "informed public discussion, regulatory review, and the establishment of guidelines for the safe development of the technology." No one had actually made a gene drive yet, but Church wanted to get the ball rolling. "The important thing is to actually listen to the public's concerns," he says. "And then try to visualize things that can go wrong and think of ways to guard against them."

To that end, he is devising new methods of biocontainment; the term normally refers to the physical safety measures (cabinets, hoods, isolation rooms) that laboratories use to prevent the escape of potentially dangerous organisms. In January, Church and members of his lab reported in the journal *Nature* that instead of relying on physical containment, they had managed to install protective measures within the microbial genome itself. They engineered a strain of bacteria that survives on a synthetic amino acid found only in the laboratory, not in nature.

And that's how Church the engineer works. No obstacle is insurmountable. Technology moves toward greater efficiency and capacity, he says, not the reverse. And in any case, doubters come with the territory. "The World Wide Web went from zero to millions of web pages in a few years," Church says. "Many revolutions look irrelevant just before they change everything swiftly."

The last time I chat with Church he is on a cell phone, walking from his office to a meeting down the street. The connection's crackly, so I ask whether he'd prefer to talk later. "I like talking and walking," he says. "It's more productive than doing just one."

I ask for an update, and he rattles off a string of developments. The company funding his data-storage project is planning to make a big announcement about his team's latest advances. "We've scaled way up from the five megabyte book," he says. He's got a paper due out in the *Proceedings of the National Academy of Sciences* about the DNA and dark matter project. His group has also completed the first successful gene drive, a small pilot study in yeast that proved that foreign genes introduced to cells in a lab can be passed on to—and spread throughout—a separate wild population.

I ask him which project he's most excited about. He answers without hesitation: CRISPR. "I like exponential fields," he says. "Right now, nothing is more exponential than that."

Church has helped launch Editas Medicine, a biotech company aimed at harnessing CRISPR's therapeutic potential. The idea is to develop a new class of CRISPR-based drugs that can "surgically repair" aberrant genes. Editas has plenty of financial and scientific backing, but it's still in early days. More than most, Church knows that ideas can often be ahead of their time. On more than one occasion, he has had to shelve a project—low-cost gene sequencing, for one—until the rest of the world was ready for it. "People think it's great to be ahead of your time," he says. "But it can actually be quite painful." We should all be grateful that's never stopped him yet.

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Manual

EDITED BY *Sophie Bushwick*

STATS

Time 8 hours

Cost \$70 (hand),

\$400 (control
board)

Difficulty



WAVE HELLO TO A SOFT ROBOT HAND



In the field of soft robotics, engineers use squishy materials to make robots durable, flexible, and safer to operate around humans. Now intrepid DIYers can also bring life to squishy machines: Last September, Harvard University published an open-access Soft Robotics Toolkit online.

Some of the materials and skills Harvard recommends may be beyond the reach of a typical garage roboticist. But with a little ingenuity, you can substitute cheaper parts and simpler techniques. This project makes actuated “fingers” out of ribbed hose from a cheap foot pump, long thin balloons (the type you can twist and fold into animals), and other basic items. By attaching five fingers to a limb—in this case, a plastic gauntlet from a set of toy

armor—you can form a robot hand.

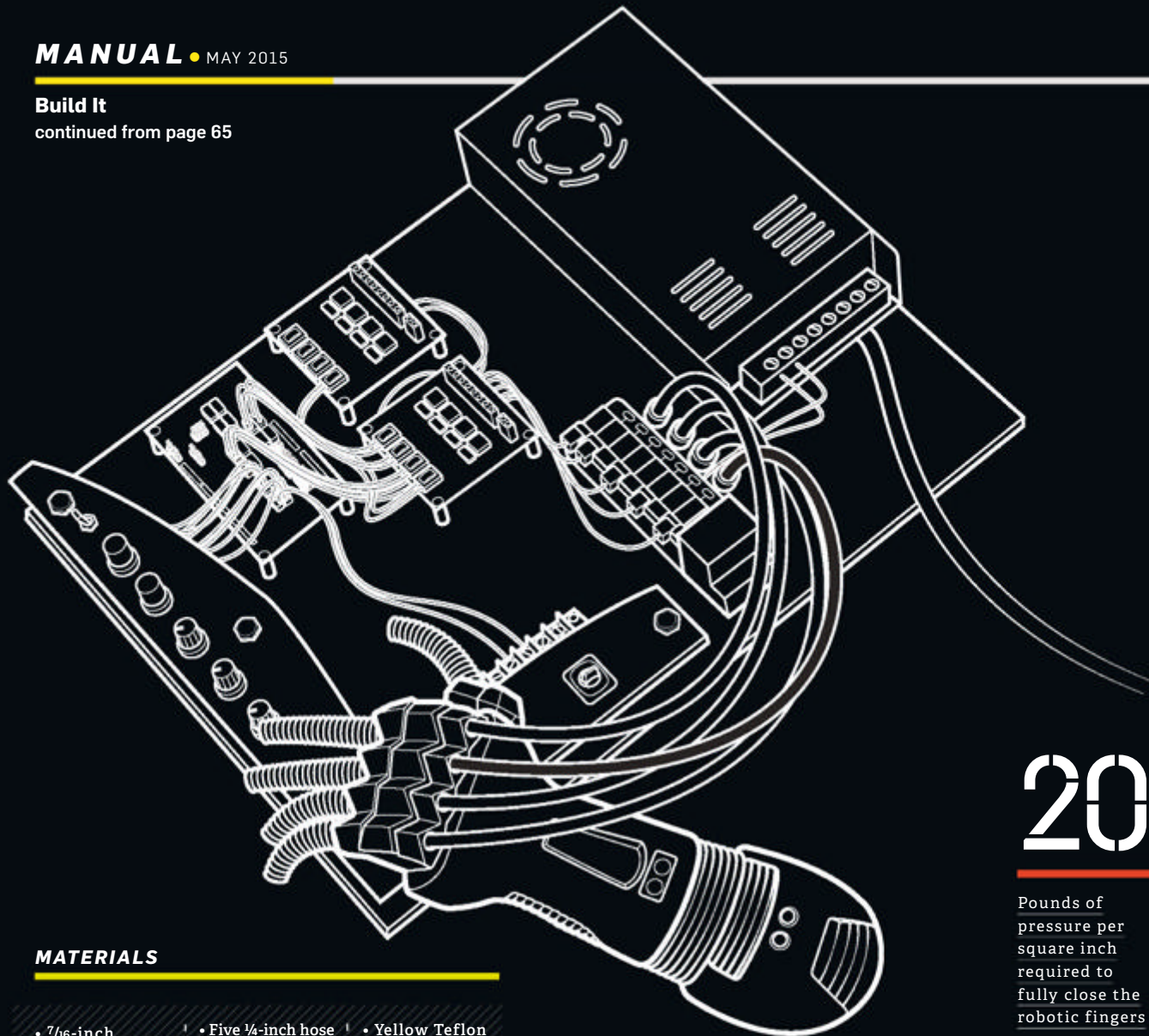
Once you’ve assembled your appendage, it’s time for phase two of the project: building a fluidic control board. The Arduino brain controls and coordinates air valves to make the hand flash the peace sign, hang loose, or even flip the bird. **ANDREW TERRANOVA**

More detailed instructions can be found at popsci.com/robohand.

continued on page 66

Build It

continued from page 65



20

Pounds of pressure per square inch required to fully close the robotic fingers

MATERIALS

- 7/16-inch inner diameter ribbed hose
- 5/16-inch wood dowel
- 1/4-inch outer diameter vinyl tubing
- Small hose clamps
- Five 1/4-inch hose barbs x 1/4-inch male threaded adapters
- Five 1/4-inch hose barbs x 1/4-inch female threaded adapters
- Electrical tape
- Yellow Teflon thread tape
- Several long balloons (type 350Q)
- 1-inch x 6-inch board or other support
- Fluidic control board

TOOLS

- | | | | |
|-----------------------|----------------------------|-------------------------------------|------------------------------|
| Utility knife | Spring-loaded center punch | Drill press and 5/16-inch drill bit | Scissors |
| Flat-head screwdriver | Hot-glue gun | Measuring tape | Adjustable crescent wrenches |

INSTRUCTIONS

- 1 Cut five finger-length pieces of ribbed hose. Notice the natural curl, and consider the upper side of the curve to be the "top" of each finger. Use a center punch and drill press to make stress-relief holes along both sides of the hose, between each rib. Insert a wooden dowel to help support the finger's shape while you do this.
- 2 Slice the top of each finger between each rib from one side to the other, ending at the stress-relief holes. Now, each finger can curl more easily.
- 3 Use a dowel to insert a balloon into each finger. Secure the closed end of the balloon to the outside of the finger's tip with electrical tape, and seal the tip with hot glue and more electrical tape.
- 4 Cut away the open ends of the balloons, leaving about an inch of balloon beyond the end of each finger. Stretch the open end of the balloon out and over the end of each finger and secure with tape.
- 5 Wrap the threads of each male hose barb with yellow Teflon tape and firmly tighten it into a female hose barb. Use more tape to wrap each female hose barb several times so it fits snugly into the open end of a finger. Secure it in place with hose clamps.
- 6 Hot-glue the five fingers to the end of the 1-inch x 6-inch board (or other support). This forms the hand. Finally, attach vinyl tubing to the open hose barbs on each finger.
- 7 Now the hand is complete—but it still needs a control system. Visit popsci.com/robohand for additional instructions.

Chicago Doctor Invents **Affordable** Hearing Aid **Outperforms** Many Higher Priced Hearing Aids

Reported by J. Page

Chicago: Board-certified physician Dr. S. Cherukuri has done it once again with his newest invention of a medical grade **ALL DIGITAL affordable hearing aid**.

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“I would definitely recommend them to my patients with hearing loss” —Amy S., Audiologist, Indiana



Dr. Cherukuri knew that many of his patients would benefit but couldn’t afford the expense of these new digital hearing aids. Generally they are *not* covered by Medicare and most private health insurance.

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Prototypes



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For 25 years, inventor Keahi Seymour has dreamed of running with the speed and loping gait of an animal. His inspiration struck at age 12, while he was watching a program about kangaroos. “The announcer said it moves at such an efficient gait by using its Achilles tendons as springs,” Seymour says. “I thought, ‘Why not replicate that in a device that could propel a human?’” He began sketching footwear using ostriches, which, he discovered, run more like humans, as his model.

By the age of 17, he had built his first prototype using old Rollerblade boots, steel tubing, and bungee cords. Then, he built some 200 more. Today, Seymour’s Bionic Boot can propel him forward at 25 miles per hour. “You really feel superhuman,” he says. Eventually, Seymour hopes to boost the speed to 40 miles per hour, perhaps by enhancing the boots’ springy heels with electrical actuators. That, he expects, will take a few more prototypes. **ALISSA ZHU**



1998

Seymour made his third prototype from wire mesh and fiberglass, powered by an “Achilles tendon” made from steel tubing and a bungee cord spring. These boots were raised 10 to 12 inches above the ground, the height that later proved the most stable. But they only reached 15 mph.



2010

To reduce the weight of subsequent prototypes from 10 pounds to 6, Seymour swapped the fiberglass for aircraft-grade aluminum. He also replaced the springs, which had been made of thin rubber wound around a carabiner or a bolt, with thick rubber spear-gun tubing.



2012

Seymour ditched the all-aluminum boot in favor of a housing molded from carbon fiber. To secure it to his legs, Seymour chose stable snowboard-boot clasps over lighter and flimsier Velcro fasteners. In later prototypes, he kept the carbon fiber but returned to Velcro, reinforcing it with nylon straps.

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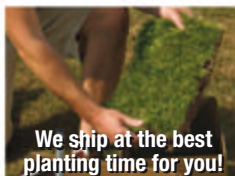
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In Rebuild, columnist **Hackett** prepares for life after the apocalypse

↓
After the apocalypse, your big, fancy television will be dead—no power, no TV. So loot the corpse and use its parts to build the original broadcast entertainment: radio.

A radio transmitter sends information across a room, or an ocean, by creating a carrier wave of alternating current. Modulating the amplitude, or height, of that wave with an electrical signal (like the one produced by a microphone) encodes sound. Amplitude modulation

(AM) was the first radio broadcast method and is still in wide use.

To pick up radio waves, I needed a receiver to isolate the signal representing audio. I built a simple crystal radio from a hulking Zenith television I found on the street. First, the radio required an antenna—the larger, the better—so I harvested wire from the TV and ran it up two flights of stairs, out the window, and down the side of the building.

Next, I built a tuned circuit to match the frequency of the carrier wave from any given station. I coiled magnet wire from the Zenith's shielding shroud around a nonconducting center, a.k.a. a beer bottle. Then, I sanded conductive points along the coil and rigged a movable connector. By changing contact points, I could change the length of the coil until I matched the desired frequency.

Pairing the coil with an adjustable capacitor made from tubes of tinfoil and paper strengthened the reception. I moved the tubes to adjust the radio's volume. The circuit then needed a diode—I found a geranium one in the TV's circuit boards. It changed the carrier wave into direct current, leaving the signal behind. Finally, a ground connection completed the circuit.

But I still needed a way to listen. Since the radio pulled electricity entirely from the radio waves, it didn't have enough power for normal headphones. A buzzer from a broken alarm clock did the trick, and I didn't mind the tinny sound.

I was somewhat shocked that the assembled radio worked. Next up is building a radio transmitter so when all media collapses, I'll be set to entertain myself.

4,705

Number of AM radio stations in the United States as of December 31, 2014

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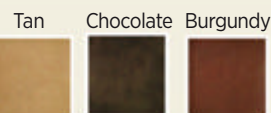
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HIJACK YOUR CAR'S INFOTAINMENT SYSTEM



As most drivers know, "infotainment" generally means "in-dash navigation system with limited function and old maps." Soup up your car's outdated software with an upgrade module and a powerful computer you already own—your smartphone. **MATT JANCER**

WARNING: Disconnect the car battery before installation, negative (black) terminal first. If you start sizzling, you've grabbed the wrong one.

MATERIALS INSTRUCTIONS

- Car
- VAIS Tech or Parrot kit
- Adhesive-backed Velcro
- Plastic or Velcro zip ties
- Smartphone

- 1 The VAIS Tech kit (for Toyota and Lexus) uses the factory touchscreen, while Parrot's universal kit includes a separate screen. Both require you to remove the car's central

- 2 Use adhesive Velcro to mount the kit's module well away from heating vents. Try putting it on the passenger side of the console, inside the console,

or in the glove compartment.

- 3 Route the wires: Y-harness to the head unit, video harness to the touchscreen. Use zip ties to bundle these cables with the wiring behind

your dash so they don't swing around.

- 4 To plug in your phone, run an AV cable and either a mini USB cable (for Android) or Lightning cable (for iPhone)

behind the dash to the module. The flat type fits well between dash panels.

- 5 Program setup varies for different kits. Consult your car's manual, and follow the activa-

tion instructions. Then, reinstall the dashboard panels.

- 6 The new operating system borrows your phone's data connection to let the module's apps navigate, play music, and more.



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Time 4 hours
Cost \$250+
Difficulty
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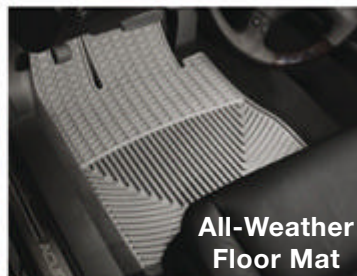
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That's a Job

Roller Coaster Designer



Structural engineer Alan Schilke specialized in designing supports for buildings and stadiums. Then one day, a roller coaster company asked him to create columns to brace its rides. When Schilke corrected the G-force calculations the company had been using for years, it hired him full time. Now, Schilke designs coasters for Ride Centerline LLC, drawing ideas from a lifetime spent soaring off BMX bike and ski jumps. **JUNNIE KWON**

How do you begin creating a new roller coaster?

I'm always thinking about what will make a coaster the most fun, which starts at the setup. In the X Games, they build 10 jumps in a



row, but they're not all the same—they avoid repetition. That's the same thing you do when designing a roller coaster.

How does it feel to ride one of your own creations?

Back in the old days, I was always amazed. But today, we make simulations of everything. There are very

The Rattler was a 20-year-old wooden roller coaster at Six Flags Fiesta Texas in San Antonio. Schilke helped upgrade its tracks, transforming it into the wood-and-steel Iron Rattler, the first hybrid coaster to include a completely inverted barrel roll.

few surprises anymore, because I've done it all virtually.

What are you working on now?

This year, we're converting two wooden roller coasters. We take an old, decrepit coaster that has outlived its life and put a steel I-box track on top of it, which upgrades it even beyond most modern coasters.

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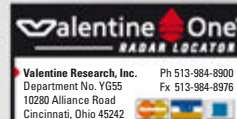
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Q:

DO BABIES EXPRESS EMOTIONS IN THE SAME WAYS ADULTS DO?

Short answer Eventually, yes.

A:

In 1986, psychology professor Linda Camras took a leave of absence from DePaul University to have a baby. For eight weeks, she recorded her daughter's every expression and what triggered it. "I did a lot of videotaping," she says. It was the first real-world test of a 1970s theory: that by 2 months old, babies automatically smile, knit their brows, and contort their faces to show positive versus negative emotions, like joy or fear.

The idea had made sense to Camras—until she started studying her own baby. "I found a lot of things that didn't fit into the theory," she says. For instance, her baby raised her eyebrows in a classic expression of surprise when playing with a familiar toy.

A baby's facial repertoire, Camras

observed, can be somewhat messy. Only with age and feedback does "it get organized so that there's a tighter link between the facial expression and the emotion," she says.

Michael Lewis, who studies child development at Rutgers Robert Wood Johnson Medical School, says, "Most people agree that by 6 to 9 months, there are facial expressions of emotions." But he believes it occurs even earlier. His lab found that when infants as young as 2 months old pulled a string that cued up pictures of smiling babies and *Sesame Street* music, their faces showed pleasure. Later, when the string was disabled, they showed anger and sadness.

Camras, however, isn't sure these effects occur outside laboratory settings and questions the assumption that a baby's face, unlike an adult's, always reveals its inner state. "If your professor slips and falls, you try not to laugh, because it's rude," Camras says. "As adults, we can control our facial behavior, but we assume babies don't do that."

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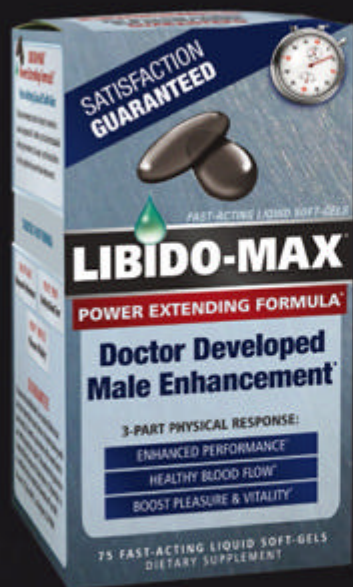
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ASK ANYTHING

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Q: Is secondhand vaping harmful to your health?

Short answer It's not as bad as secondhand smoking.

A:

A small but disturbing study published last summer found that vaping indoors—even in a well-ventilated room—releases ultra-fine particles and potentially carcinogenic hydrocarbons into the air. “Our data confirm that e-cigarettes are not emission-free,” the authors wrote. Still, studies of exhaled vapor find that such emissions turn up at concentrations so low they may not pose much of a health risk to bystanders (or vapers).

The Food and Drug Administration, which may be called upon to regulate e-cigarettes, remains cagey: “More data is needed to determine the constituents in e-cigarette aerosols and the potential risks of secondhand exposure.” But Igor Burstyn, an occupational health expert at Drexel University, argues they're being overcautious. “It's propaganda mixed with willful ignorance,” he says. “There are thousands of measurements from devices on the market.” His 2014 e-cigarette data review concluded that contaminants “pose no apparent concern” to bystanders.

This we can say for certain: You're better off breathing in vapor than secondhand smoke. Tobacco smoke contains thousands of chemicals, 60 of them known carcinogens, says toxicologist Maciej Goniewicz. “In vapor, we find just a few of these, at much lower levels.”

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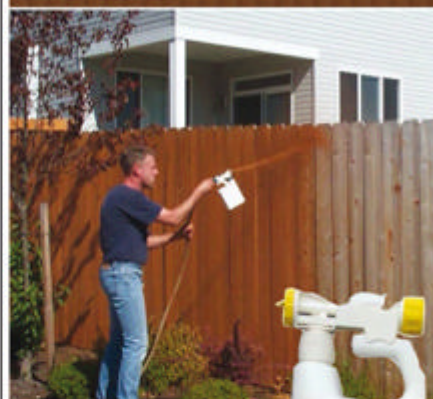


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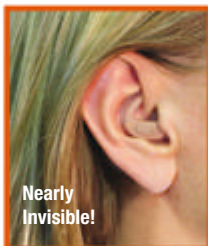
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THE NEW TOOLS OF HOME IMPROVEMENT



In April 1956, *Popular Science* told readers how to modernize homes with bleeding-edge technology. The mark of a great home, we noted, “is not its size or shape or color, but how much up-to-date machinery it has to make living easier.” At the time, that meant retractable electrical cords, smokeless ovens, and countertop blenders. Today, that means something entirely different: app-based security systems, voice-controlled lighting, and cloud-based intelligence that learns your daily routine and adjusts the heat or AC to your liking—before you even walk in the door. To learn how to set up today’s smart home, turn to page 58. **JUNNIE KWON**

359

Billions of dollars Americans spent on home improvements between 2009 and 2011

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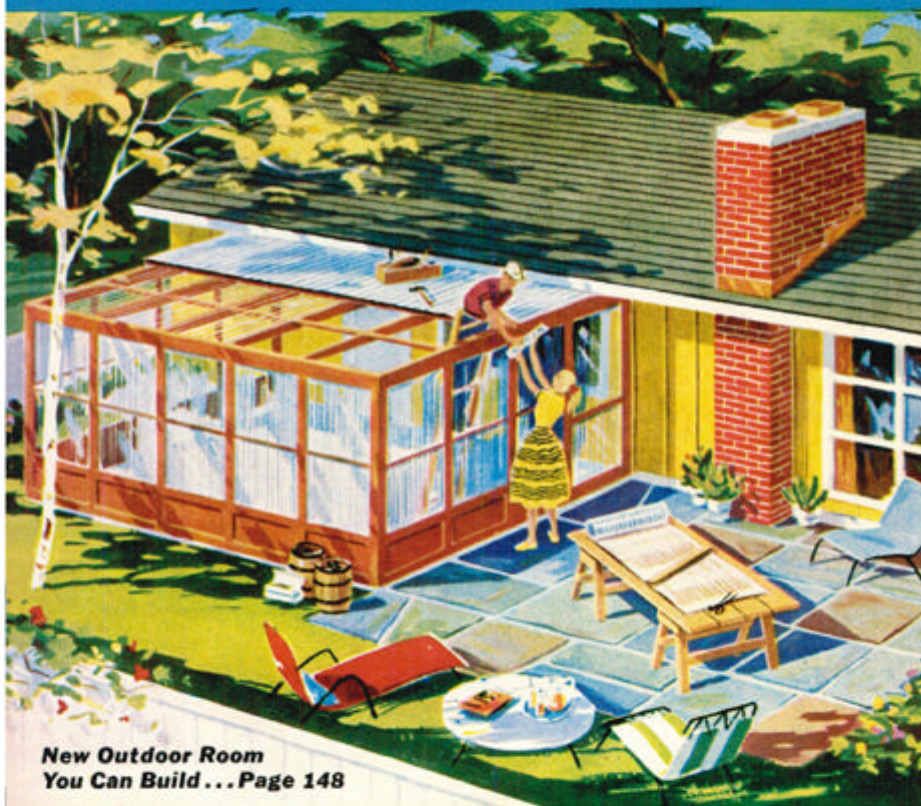
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HOME SHOW

10 Ways to Improve the Home You Have
A House Designed for Do-It-Yourselfers
What You Should Know About Appliances



THE SMART HOME, CIRCA 1990

In 1990, Dutch astronomer Chriet Titulaer built his House of the Future, a \$6-million mock-up of how we would live in 10 years. As *Popular Science* reported that September, it included state-of-the-art technologies—some of which came to fruition just a few years late.

Personalized Security

From six feet away, the front door recognized the owner's unique chip card and automatically granted entry.

Intelligent Fuel Indicator

A sensor monitored gas consumption and used data such as indoor and outdoor temperature to help decrease utility bills.

Automatic Meal Delivery

A conveyor carried meals from the kitchen to a cube-shaped glass solarium in an ornamental pond outside.

Virtual Chef

A central column in the kitchen housed a refrigerator, a freezer, food storage, and a computer that offered recipes onscreen or by voice.

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